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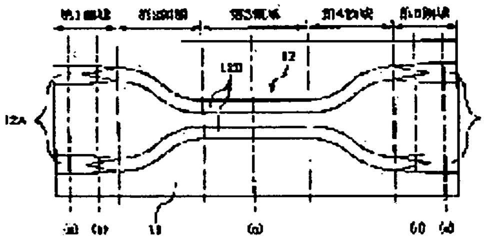
(54) OPTICAL DIRECTIONAL COUPLER

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a small-sized and low loss optical directional coupler connectable to an optical fiber with high coupling efficiency.
SOLUTION: This optical directional coupler is provided with two pieces of optical waveguides provided ranging first to fifth areas continuing along a propagational direction of a beam, and in the first, fifth areas, an interval between respective cores 12 is widened relatively, and in the third area, the interval between respective cores 12 is narrowed relatively so that the beams propagating through respective optical waveguides mutually act. Respective optical waveguides are provided with the double structural core consisting of an outer core 12A and an inner core 12B, and the refractive index of the inner core 12B is made higher than the same of the outer core 12A so that at least a specific refractive index difference between the core and a clad in the third area becomes larger than the specific refractive index difference in the first, fifth areas.



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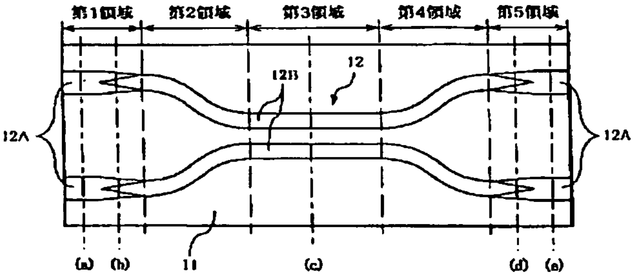
(54)【発明の名称】　光方向性結合器

(57)【要約】

【課題】光ファイバと高い結合効率で接続可能な小型で低損失の光方向性結合器を提供する。

【解決手段】本光方向性結合器は、光の伝搬方向に沿って連続する第１～５領域に亘って設けられた２本の光導波路を有し、第１、５領域では、各コア１２間の間隔が相対的に広くされ、第３領域では、各光導波路内を伝搬する光が相互作用するように各コア１２間の間隔が相対的に狭くされている。各光導波路は、アウターコア１２Ａ及びインナーコア１２Ｂからなる２重構造のコアを備え、少なくとも第３領域におけるコアとクラッドとの比屈折率差が、第１、５領域における比屈折率差よりも大きくなるように、インナーコア１２Ｂの屈折率がアウターコア１２Ａの屈折率よりも高くされている。



【特許請求の範囲】

【請求項１】光の伝搬方向に沿って連続する第１～５領域に亘って設けられた２本の光導波路を有し、光が入出射される第１領域及び第５領域では、前記各光導波路内を光が独立して伝搬するように各光導波路間の間隔が相対的に広くされ、第３領域では、前記各光導波路内を伝搬する光が相互作用するように各光導波路間の間隔が相対的に狭くされ、第２領域及び第４領域では、隣接する領域の各光導波路がそれぞれ連結される構成の光方向性結合器において、

前記各光導波路は、少なくとも第３領域におけるコアとクラッドとの比屈折率差が、第１領域及び第５領域におけるコアとクラッドとの比屈折率差よりも大きいことを特徴とする光方向性結合器。

【請求項２】前記各光導波路は、少なくとも第３領域におけるコアの屈折率が互いに略等しいことを特徴とする請求項１記載の光方向性結合器。

【請求項３】前記各光導波路は、相対的に高い屈折率を有する内側コア及び相対的に低い屈折率を有する外側コアからなる２重構造のコアをそれぞれ備え、少なくとも第３領域に位置する前記各光導波路のコア幅が、それぞれ前記内側コアの幅とされたことを特徴とする請求項１または２記載の光方向性結合器。

【請求項４】少なくとも第３領域に位置する前記各光導波路のコアの間に設けられ、クラッドの屈折率よりも低い屈折率を持つ低屈折率領域を備えて構成されたことを特徴とする請求項１～３のいずれか１つに記載の光方向性結合器。

【請求項５】前記低屈折率領域が、空気層により形成されたことを特徴とする請求項４記載の光方向性結合器。

【請求項６】前記各光導波路は、前記低屈折率領域の設けられている部分のコア幅が他の部分のコア幅よりも狭いことを特徴とする請求項４または５記載の光方向性結合器。

【請求項７】前記低屈折率領域は、少なくとも第３領域に位置する前記各光導波路のコアの間及び各コアの外側に設けられたことを特徴とする請求項４～６のいずれか１つに記載の光方向性結合器。

【請求項８】光の伝搬方向に沿って連続する第１～９領域に亘って設けられた２本の光導波路を有し、光が入出射される第１領域及び第９領域では、前記各光導波路内を光が独立して伝搬するように各光導波路間の間隔が相対的に広くされ、第３～７領域では、前記各光導波路内を伝搬する光が相互作用するように各光導波路間の間隔が相対的に狭くされ、第２領域及び第８領域では、隣接する領域の各光導波路がそれぞれ連結される構成の光方向性結合器において、

第５領域に位置する前記各光導波路間の間隔が、第３領域及び第７領域に位置する前記各光導波路間の間隔よりも狭くされ、第５領域の各光導波路が、第４領域及び第６領域を介して第３領域及び第７領域の各光導波路に連結される構成としたことを特徴とする光方向性結合器。

【請求項９】前記各光導波路は、少なくとも第５領域に位置するコアの幅が他の領域に位置するコアの幅よりも狭いことを特徴とする請求項８記載の光方向性結合器。

【請求項１０】少なくとも第３～７領域に位置する前記各光導波路のコアの間に設けられ、クラッドの屈折率よりも低い屈折率を持つ低屈折率領域を備えて構成されたことを特徴とする請求項８または９記載の光方向性結合器。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、光導波路を用いる光方向性結合器に関し、特に、光ファイバと高い結合効率で接続可能な小型で低損失の光方向性結合器に関する。

【０００２】

【従来の技術】一般に、光導波路を用いて構成される光方向性結合器は、光の分岐や合波、伝搬経路の変更等を行うための光デバイスであり、例えば、光導波路型の波長フィルタや干渉計の要素部品などに用いられる。従来の光方向性結合器には、例えば図２９に示すように、光導波路の２つのコアを狭い間隔で平行に配置した光結合部と、コアが比較的広い間隔で配置された入出射部と、光結合部と入出射部とをつなぐ連結部とを有するものがある。この従来の方向性結合器においては、入出射部、光結合部及び連結部のそれぞれについて、光の進行方向に垂直なコア断面の形状が同一であり、また、コアとクラッドの比屈折率差が同一である。

【０００３】上記のような構造の光方向性結合器において、ガイドされる光のモードサイズが１０μm程度のシングルモードファイバとの結合効率を向上させようとすると、光方向性結合器を構成する光導波路のコアサイズと比屈折率差を、シングルモードファイバのコアサイズと比屈折率差に近づける必要がある。

【０００４】

【発明が解決しようとする課題】しかしながら、従来の光方向性結合器では、光導波路のコアサイズと比屈折率差をシングルモードファイバに近づけた場合に光方向性結合器を低損失にしようとすると、光結合部を長くする必要が生じるため、光方向性結合器が大型化してしまうという問題があった。

【０００５】ここで、光方向性結合器を構成する光導波路のコアサイズや比屈折率差と光結合部の長さとの関係について簡単に説明する。まず、コアとクラッドの比屈折率差Δを、コアの屈折率n_1、クラッドの屈折率n_2を用いて次のように定義する。

$$\Delta = (n_1 - n_2) / n_2 \quad \cdots (1)$$

光導波路と光ファイバとの結合効率は、図３０に示すように、光導波路の比屈折率差Δが光ファイバの比屈折率

差と同程度の値となるときに最も高くなり、その値よりも比屈折率差Δが大きくなると結合効率は低下する。また、図示しないが、光導波路のコアサイズについては、光ファイバのコア径と同程度の値のときに結合効率が最も高くなり、光ファイバのコア径よりも光導波路のコアサイズが小さくなると、結合効率は低下する。

【０００６】光方向性結合器の比屈折率差Δとコアの大きさに関しては、光導波路をシングルモード導波路とするための制約として、比屈折率差Δを大きくするほど、コアの大きさを小さくしなければならないということがある。図３１及び図３２は、光方向性結合器の光結合部のギャップ幅（２つのコアの間隔）に対する結合長の関係を示したものである。ただし、図３１には、コアサイズ（コアを正方形としたときの一辺の大きさ）を一定として、比屈折率差Δを変化させたときの関係が示してあり、図３２には、比屈折率差Δを一定として、コアサイズを変化させたときの関係が示してある。ここで結合長とは、一方のコアから他方のコアへ移動する光パワーが１００％になる最短長さとする。

【０００７】図に示すように、コアサイズと比屈折率差Δが一定であればギャップ幅が小さいほど結合長が短くなり、コアサイズとギャップ幅が一定であれば比屈折率差Δが小さいほど結合長が短くなる。また、比屈折率差Δとギャップ幅が一定であればコアサイズが小さくなるほど結合長は短くなる。図３３は、光方向性結合器の光結合部のギャップ幅に対する光結合部の損失の関係を、比屈折率差Δに応じて示したものである。ただし、コアサイズは一定である。

【０００８】図３３に示すように、光結合部における損失に着目すると、比屈折率差Δが一定であればギャップ幅が大きいほど損失が小さくなり、ギャップ幅が一定であれば比屈折率差Δが大きいほど損失は小さくなる。この理由は、次のように説明される。図３４に示すように、光方向性結合器の光結合部における光パワーの移動は、０次モードと１次モードとの結合によって生ずる。即ち、図３４の上段に示した２つの光導波路のうちの上側の光導波路の左端から入力されたシングルモード光は、光結合部を伝搬する際に、図３４（Ｉ）に示すような０次モードの電界分布と、図３４（II）に示すような１次モードの電界分布とをもつようになり、図３４（III）に示すような両モードの重ね合わせによる電界分布が生じることになる。

【０００９】この際、光結合部の入射部（Ａ）及び出射部（Ｅ）における０次モードの電界分布の中央部分の窪みの極小値（これをＩ１とする）が小さいほど、２つのモードを加算したときのモード形状が、片方の光導波路に導波されるモード形状に近づくため、光結合部に損失が小さくなる。逆に、窪みの極小値Ｉ１が大きいと、０次モードの電界分布が綺麗な２つの山に別れないため、２つのモードを加算したときのモード形状が、片方の光導波路に導波されるモード形状とならない（他方の光導波路を導波される成分が増える）ため、その分だけ損失が大きくなる。

【００１０】０次モードの中央部分の窪みの極小値Ｉ１は、コアサイズ及び比屈折率差Δが一定であればギャップ幅が大きいほど小さくなり、比屈折率差Δとギャップ幅が一定であればコアサイズが大きいほど小さくなり、また、ギャップ幅とコアサイズが一定であれば比屈折率差Δが大きいほど小さくなるという関係がある。図３５は、０次モードのピーク強度をＩ０として、Ｉ１／Ｉ０が一定になる場合（即ち、損失が一定になる場合）の比屈折率差Δと結合長の関係を、コアサイズに応じて示したものである。図３５に示すように、コアサイズが大きくても小さくても、比屈折率差Δを大きくするほど結合長が短くなることがわかる。

【００１１】従って、小型で低損失の光方向性結合器を実現する１つの手段としては、コアとクラッドの比屈折率差Δを大きくし、それに応じてコアサイズを調整することが有効であると考えられる。光導波路の屈折率分布に特徴を持たせた方向性結合型の光デバイスとしては、例えば、特開平４－１９７１３号公報等に記載された導波型光スイッチが公知である。この導波型光スイッチは、近接する２つの光導波路の屈折率差を大きくする、即ち、光結合部に位置する光導波路の各コアの屈折率に違いを持たせることで、０次モードと１次モードの伝搬定数（伝搬速度）の差を大きくしようとしたものである。

【００１２】しかし、上記の導波型光スイッチでは、図３６に示すように、光結合部における０次モード及び１次モードの電界強度分布が、２つの光導波路において非対称となるため、干渉後の電界強度分布が単峰にはならない。このため、上記のような公知技術を屈折率固定の光方向性結合器に適用した場合には、損失の増加や消光比の低下といった問題が生じることになる。

【００１３】本発明は上記の点に着目してなされたもので、光ファイバと高い結合効率で接続可能な小型で低損失の光方向性結合器を提供することを目的とする。

【００１４】

【課題を解決するための手段】このため本発明の光方向性結合器は、光の伝搬方向に沿って連続する第１～５領域に亘って設けられた２本の光導波路を有し、光が入出射される第１領域及び第５領域では、前記各光導波路内を光が独立して伝搬するように各光導波路間の間隔が相対的に広くされ、第３領域では、前記各光導波路内を伝搬する光が相互作用するように各光導波路間の間隔が相対的に狭くされ、第２領域及び第４領域では、隣接する領域の各光導波路がそれぞれ連結される構成の光方向性結合器において、前記各光導波路は、少なくとも第３領域におけるコアとクラッドとの比屈折率差が、第１領域及び第５領域におけるコアとクラッドとの比屈折率差よ

りも大きくしたものである。

【００１５】かかる構成によれば、例えば、第１領域の一方の光導波路に入射された光は、第２領域を介して第３領域に伝搬される。第３領域では、２つの光導波路が接近しているため一方の光導波路を伝搬してきた光が他方の光導波路から出力され、第４領域を介して第５領域に伝搬される。この際、光結合が行われる第３領域の比屈折率差が第１領域及び第５領域よりも大きくされていることで、第３領域の長さ、即ち、結合長が短くなる。また、第１領域及び第５領域の比屈折率差は小さいので、高い結合効率で光ファイバと接続可能となる。

【００１６】また、前記各光導波路は、少なくとも第３領域におけるコアの屈折率が互いに略等しくなるようにするのが好ましい。２つの光導波路の各コアの屈折率を略等しくすることで、第３領域の各光導波路における０次モード及び１次モードの電界強度が対称的な分布となるため、干渉後の電界強度分布がほぼ単峰となり、光結合の際の損失が低くなる。

【００１７】さらに、前記各光導波路の具体的な構成としては、相対的に高い屈折率を有する内側コア及び相対的に低い屈折率を有する外側コアからなる２重構造のコアをそれぞれ備え、少なくとも第３領域に位置する前記各光導波路のコア幅が、それぞれ前記内側コアの幅とされるようにしてもよい。加えて、上記の光方向性結合器については、少なくとも第３領域に位置する前記各光導波路のコアの間に設けられ、クラッドの屈折率よりも低い屈折率を持つ低屈折率領域を備えて構成されるのが好ましい。この低屈折率領域は、空気層により形成してもよい。このように低屈折率領域を設けることで、第３領域の比屈折率差がより大きくなって結合長が短くなるとともに、光結合部のコア間の屈折率が低くなって損失が小さくなる。

【００１８】また、前記各光導波路は、前記低屈折率領域の設けられている部分のコア幅が他の部分のコア幅よりも狭くなるようにするのが好ましい。これにより光結合部コアサイズが小さくなって結合長がさらに短くなる。さらに、前記低屈折率領域は、少なくとも第３領域に位置する前記各光導波路のコアの間及び各コアの外側に設けられるようにしてもよい。このようにすることで、第３領域におけるコアとクラッドの比屈折率差が一層大きくなる。

【００１９】また、本発明に係る他の光方向性結合器は、光の伝搬方向に沿って連続する第１～９領域に亘って設けられた２本の光導波路を有し、光が入出射される第１領域及び第９領域では、前記各光導波路内を光が独立して伝搬するように各光導波路間の間隔が相対的に広くされ、第３～７領域では、前記各光導波路内を伝搬する光が相互作用するように各光導波路間の間隔が相対的に狭くされ、第２領域及び第８領域では、隣接する領域の各光導波路がそれぞれ連結される構成の光方向性結合器において、第５領域に位置する前記各光導波路間の間隔が、第３領域及び第７領域に位置する前記各光導波路間の間隔よりも狭くされ、第５領域の各光導波路が、第４領域及び第６領域を介して第３領域及び第７領域の各光導波路に連結される構成としたものである。

【００２０】かかる構成によれば、光結合部となる第３～７領域のうちの中央部分に位置する第５領域が強光結合領域となるので結合長が短くなるとともに、第３、７領域の各コア間の間隔が第５領域のコア間隔よりも広くなっているので、光結合部における損失が低く抑えられるようになる。さらに、前記各光導波路は、少なくとも第５領域に位置するコアの幅が他の領域に位置するコアの幅よりも狭くなるようにしてもよい。加えて、上記の光方向性結合器については、少なくとも第３～７領域に位置する前記各光導波路のコアの間に設けられ、クラッドの屈折率よりも低い屈折率を持つ低屈折率領域を備えて構成されるのが好ましい。

【００２１】

【発明の実施の形態】以下、本発明の実施形態を図面に基づいて説明する。図１は、第１の実施形態に係る光方向性結合器の構成を示す上面図である。また、図２は、図１の一点鎖線で示す(a)～(e)における断面図である。図において、本光方向性結合器は、例えば、シリコン基板１０と、該シリコン基板１０上にポリイミド等を用いて形成された光導波路層とから構成される。光導波路層は、クラッド１１に囲まれた２つのコア１２からなり、各コア１２は、図１で左右方向に平行に形成され、互いの間隔が中央部分において狭くなっている。ここでは、図１で左右端に位置する部分（入出射部）を第１領域及び第５領域とし、中央に位置する各コア１２の間隔が狭くなった部分（光結合部）を第３領域とし、第１領域及び第５領域と第３領域との間に位置する部分（連結部）を第２領域及び第４領域とする。

【００２２】各コア１２は、外側に位置するコア（アウターコア）１２Ａ及び内側に位置するコア（インナーコア）１２Ｂとからなるダブルコア構造を有している。アウターコア１２Ａは、例えばシングルモードファイバ等との接続が行われる第１領域及び第５領域の端部付近に形成され（図２(a)(e)参照）、接続端面において広い断面積を有することにより高い結合効率でシングルモードファイバとの接続が可能となる。インナーコア１２Ｂは、断面積がアウターコア１２Ａよりも狭くしてあり、第２領域～第４領域にかけて形成されている。また、２つのコア１２の対向する部分の屈折率は互いに略等しくなるようにしてあり、２つのコア１２が対称的な構造をもつように設定されている。

【００２３】アウターコア１２Ａからインナーコア１２Ｂへの変換は、例えば、第１領域及び第５領域内において、テーパー状に形成した各コアを接合させることで行われる。この変換部分のコア断面が、図２(b)(d)に示す

ように２重構造となる。なお、アウターコア１２Ａからインナーコア１２Ｂへの変換を第１領域及び第５領域内で行うようにしたが、これに限らず、第２領域及び第４領域内で行うようにしてもよい。ただし、第１領域及び第５領域内で変換を行えば、第２領域及び第４領域のコアを細くでき曲率半径を小さくできるので、光方向性結合器がより小型のものとなる。

【００２４】アウターコア１２Ａの屈折率（n_{1o}）は、クラッド１１の屈折率（n_2 ）よりも高く、インナーコア１２Ｂの屈折率（n_{1i}）は、アウターコア１２Ａの屈折率（n_{1o}）よりも高くしてある。即ち、光導波路の屈折率は次のような大小関係をもつように設定される。

$n_{1i} > n_{1o} > n_2$

ここで、第１の実施形態における各設定値の具体例を示しておく。インナーコア１２Ｂについては、コアサイズを幅Ｗ１＝４μｍ×高さＨ１＝７μｍとし、屈折率n_{1i}を1.532 とする。アウターコア１２Ａについては、コアサイズを幅Ｗ２＝７μｍ×高さＨ２＝７μｍとし、屈折率n_{1o}を1.528 とする。クラッド１１については、屈折率n_2 を1.520 とし、アンダークラッドの厚さを１０μｍ、オーバークラッドの厚さを１５μｍとする。また、このような設定では、第３領域におけるコア間のギャップ幅Ｇ１を5.5 μｍとすると、結合長は5.4 ｍｍとなる。

【００２５】また、上述したダブルコア構造の形成方法について簡単に説明する。図３は、例えば、フッ素化ポリイミドを用いたダブルコア構造の形成方法である。なお、ここではフッ素化ポリイミドを用いたが、本発明はこれに限られるものではない。ただし、フッ素化ポリイミドのような有機材料を用いると、ダブルコア構造を比較的容易に作製できる。

【００２６】図3において、まず、クラッド層、アウターコア層及びインナーコア層がスピンコートによりシリコン基板１０上に順次形成される。次に、インナーコア幅に相当するマスクをインナーコア層上に形成した後、リアクティブイオンエッチング（ＲＩＥ）によってインナーコア層及びアウターコア層の一部をエッチングし、さらに、インナーコアを囲むようにアウターコア層が塗布される。

【００２７】次に、第１領域または第５領域に位置するダブルコア部分を形成する場合には、アウターコア幅に相当するマスクをアウターコア層上に形成した後、ＲＩＥによって不要なアウターコア層を除去してアウターコアを形成し、さらにアウターコアを囲むようにクラッド層が塗布されて、第１領域または第５領域のダブルコア構造が形成される。一方、第２～第４領域に位置するコア部分を形成する場合には、インナーコア幅に相当するマスクをアウターコア層上に形成した後、ＲＩＥによって不要なアウターコア層を除去する。ただし、この場合にはインナーコアの上下にアウターコアが残存することになる。そして、コアを囲むようにクラッド層が塗布されて、第２～第４領域のダブルコア構造が形成される。

【００２８】上記のようにして形成されたダブルコア構造を有する光方向性結合器では、シングルモードファイバとの接続において、コアサイズの大きなアウターコア１２Ａと接続されるので、従来の光方向性結合器よりも高い結合効率が実現される。一方、第３領域の光結合部では、屈折率を高くしたインナーコア１２Ｂが形成され、クラッド１１とコア１２の比屈折率差Δが大きくなっているため、結合長（第３領域の長さ）を短くできる。具体的には、屈折率を高くしたインナーコアを持たない従来の光方向性結合器（例えば、コア幅が７μｍ、比屈折率差Δが0.5など）では、結合長が10ｍｍ程度となるが、本実施形態の構造を用いることにより、結合長は5.4 ｍｍ程度となる。従って、比較的低損失で小型の光方向性結合器を実現できる。また、光結合部では、コア１２の幅がインナーコア幅とされており、この幅の設定を適宜に調節することによって、比屈折率差Δが大きくなってもシングルモードを保つことが可能である。

【００２９】次に、本発明の第２の実施形態について説明する。図４は、第２の実施形態に係る光方向性結合器の構成を示す上面図である。また、図５は、図４の一点鎖線で示す(a) ～(c) における断面図である。図において、本光方向性結合器は、シリコン基板１０上にクラッド１１に囲まれた２つのコア１２を形成し、そのクラッド１１とコア１２の比屈折率差Δを大きくするために、少なくとも第３領域（光結合部）に位置する各コア間に低屈折率領域１３を設けた構成とする。

【００３０】各コア１２は、第１の実施形態の場合とは異なり、単一のコアサイズ及び屈折率（n_1 ）を有するものとする。具体例を示すと、コアサイズを幅Ｗ３＝７μｍ×高さＨ３＝７μｍとし、屈折率n_1 を1.530 とする。また、各コア間のギャップ幅Ｇ２を5.5 μｍとする。さらに、クラッド１１については、その屈折率n_2 を1.522 とする。

【００３１】低屈折率領域１３は、第３領域における各コア１２間のギャップ幅以下の幅をもち、クラッド１１の屈折率n_2 より低い屈折率n_3 を持つ領域である。この低屈折率領域１３は、例えばポリイミドを用いた光方向性結合器では、エッチングにより溝を形成し、そこにクラッド１１より低屈折率な物質を塗布すれば形成できる。低屈折率領域１３の断面形状は、例えば図６(A) ～(D) などに示すような種々の形状とすることが可能である。ここでは、低屈折率領域１３の具体的な設定例として、幅Ｗ４＝４μｍ×深さＤ４＝４μｍ×長さＬ４＝6000μｍとし、屈折率n_3 を1.520 とする。

【００３２】上記のような構造の光方向性結合器によれば、光結合部における比屈折率差Δを大きくすることができるので、結合長を短くできる。また、比屈折率差Δは、低屈折率領域１３の幅、深さや屈折率n_3 を変える

ことにより調節できる。さらに、光結合部におけるコアの間の屈折率が下がることから、上述の図３４（Ｉ）に示した０次モードの電界分布の中央部分の窪みの極小値Ｉ１が低くなるため、光結合部での損失を低くすることができる。従って、第２の実施形態によれば、第１の実施形態の場合と同様にシングルモードファイバと高い結合効率で接続でき、かつ、低損失で小型の光方向性結合器を実現することができる。

【００３３】次に、本発明の第３の実施形態について説明する。図７は、第３の実施形態に係る光方向性結合器の構成を示す上面図である。また、図８は、図７の一点鎖線で示す(a) ～(c) における断面図である。図において、本光方向性結合器は、第２の実施形態の光方向性結合器について、低屈折率領域１３に代えてエアギャップ（空気層）１４を設けたものである。上記以外の構成は、第２の実施形態の構成と同様である。

【００３４】エアギャップ１４は、石英系やフッ素化ポリイミドを用いた光導波路であれば、エッチングにより簡易に作製することができる。また、エアギャップ１４の断面形状は、上述した低屈折率領域１３の断面形状の場合と同様に、例えば図９(A) ～(D) などに示すような種々の形状とすることが可能である。ここでは、エアギャップ１４の具体例として、幅Ｗ５＝４μm×深さＤ５＝４μm×長さＬ５＝6000μmのものを用いる。

【００３５】上記のような構造の光方向性結合器によれば、第２の実施形態の場合と同様に、光結合部における比屈折率差Δを大きくすることができるので、結合長を短くできる。また、比屈折率差Δは、エアギャップ１４の幅や深さを変えることにより調節可能である。さらに、光結合部におけるコアの間の屈折率が下がることから、光結合部での損失を低くすることもできる。加えて、エアギャップ１４は、低屈折率領域１３に比べて容易に形成することができるという利点もある。

【００３６】次に、本発明の第４の実施形態について説明する。図１０は、第４の実施形態に係る光方向性結合器の構成を示す上面図である。また、図１１は、図１０の一点鎖線で示す(a) ～(c) における断面図である。図において、本光方向性結合器は、第２の実施形態の光方向性結合器について、コアサイズが全長に亘って均一な２つのコア１２に代えて、第３領域に位置する部分のコアサイズを他の領域に位置する部分よりも小さくした２つのコア１２’を設けたものである。上記以外の構成は、第２の実施形態の構成と同様である。

【００３７】各コア１２’は、第１領域及び第５領域に位置する部分については、第２の実施形態で用いたコア１２と同様のサイズを有し、第３の部分に位置する部分のサイズが、例えば、幅Ｗ６＝４μm×高さＨ６＝４μmとされ、第２領域及び第４領域に位置する部分が、テーパー状に形成されて第３領域と第１領域及び第５領域とをつないでいる。また、各領域におけるコアの屈折率 n_1 は等しくなるように設定され、例えば、屈折率 n_1 ＝1.530 とされる。このコア１２’を用いた場合の比屈折率差Δは、低屈折率領域１３の幅や深さ等を変えることにより調節できる。

【００３８】かかる構成によれば、比屈折率差Δが一定の場合、コアサイズが大きくなると光導波路がマルチモードになる。シングルモード導披路の場合、コアサイズを小さくするほど比屈折率差Δを大きくすることができる。上述の図３５に示したように、比屈折率差Δを大きくし、かつ、コアサイズを小さくすれば、シングルモードを保ったままで結合長を短くできる。従って、上記の構成によれば、より低損失でより小型の光方向性結合器が実現されることになる。また、第１領域及び第５領域に位置する部分では、コアサイズが大さいので、シングルモードファイバとの結合効率が高く維持される。

【００３９】なお、上述した第４の実施形態では、第３領域に位置する部分のコアを細くするようにしたが、図１２に示すように、光結合部だけでなく、第２領域及び第４領域に位置する部分のコアも細くしてもよい。このようにすれば、第２領域及び第４領域の曲がり部分の曲率を小さくすることができるので、光方向性結合器を更に小型にすることができる。また、上述の第４の実施形態の低屈折率領域１３は、第３の実施形態の場合と同様にエアギャップ１４に代えても構わない。

【００４０】次に、本発明の第５の実施形態について説明する。図１３は、第５の実施形態に係る光方向性結合器の構成を示す上面図である。また、図１４は、図１３の一点鎖線で示す(a) ～(e) における断面図である。図において、本光方向性結合器は、上述した第１の実施形態のダブルコア構造の光方向性結合器について、第３の実施形態の場合と同様に、少なくとも第３領域の各コア間にエアギャップ１４を設けて、クラッド１１とコア１２Ｂの比屈折率差Δを大きくしたものである。なお、ここで用いたエアギャップ１４は、上述した第２の実施形態の場合と同様の低屈折率領域１３とすることもできる。

【００４１】このような構成の光方向性結合器では、ダブルコア構造としたことで、シングルモードファイバとの結合効率を下げることなく光結合部における比屈折率差Δを大きくできるので、結合長を一層短くできる。また、エアギャップ１４を設けたことで、上述した０次モードの中央部分の窪みの極小値Ｉ１を低くすることができるので、光結合部での損失を低くできる。

【００４２】次に、本発明の第６の実施形態について説明する。図１５は、第６の実施形態に係る光方向性結合器の構成を示す上面図である。また、図１６は、図１５の一点鎖線で示す(a) ～(c) における断面図である。図において、本光方向性結合器は、第２の実施形態の光方向性結合器について、クラッド１１とコア１２の比屈折率差Δをより大きくするために、少なくとも第３領域に

おいて、各コア１２の間だけでなく各コア１２の外側にも低屈折率領域１３’を設けたものである。その他の構成は、第２の実施形態の構成と同様である。

【００４３】低屈折率領域１３’は、ここでは、第１、２領域の境界付近から第４、５領域の境界付近に亘って形成され、その断面形状は、図１６(b) に示すように、２つのコア１２の間及び各コア１２の外側に突出した部分を有する。なお、低屈折率領域１３’の断面形状は、図１７(A) ～(D) などに示すような種々の形状とすることが可能である。この低屈折率領域１３’の幅や深さ等を変えることで、クラッド１１とコア１２の比屈折率差Δを適宜に調整することが可能である。

【００４４】このような構成の光方向性結合器では、第２の実施形態の場合に比べて、光結合部における比屈折率差Δがさらに大きくなるので、結合長をより短くすることが可能である。また、第２の実施形態の場合と同様に、各コア１２間の屈折率が下がることから、０次モードの中央の窪みの極小値Ｉ１は小さくなり、低損失となる。従って、第６の実施形態によれば、より小型で低損失の光方向性結合器を実現することができる。

【００４５】次に、本発明の第７の実施形態について説明する。図１８は、第７の実施形態に係る光方向性結合器の構成を示す上面図である。また、図１９は、図１８の一点鎖線で示す(a) ～(c) における断面図である。図において、本光方向性結合器は、第６の実施形態の光方向性結合器について、低屈折率領域１３’に代えてエアギャップ（空気層）１４’を設けたものである。この構成は、第３の実施形態で用いたエアギャップ１４をエアギャップ１４’に代えたものとも同様である。上記以外の構成は、第６の実施形態の構成と同様である。

【００４６】このエアギャップ１４’は、石英系やフッ素化ポリイミドを用いた光導波路であれば、エッチングにより簡易に作製することができる。また、エアギャップ１４’の断面形状は、上述した低屈折率領域１３’の断面形状の場合と同様に、例えば図２０(A) ～(D) などに示すような種々の形状とすることが可能である。このエアギャップ１４’の幅や深さ等を変えることで、クラッド１１とコア１２の比屈折率差Δを適宜に調整することが可能である。

【００４７】上記のような構造の光方向性結合器によれば、第６の実施形態の場合と同様に、光結合部における比屈折率差Δがさらに大きくなるので、結合長をより短くでき、また、光結合部における損失も低くできる。さらに、エアギャップ１４’は、低屈折率領域１３’に比べて容易に形成することができるという利点もある。なお、上述の第６、７の実施形態では、第２、３の実施形態について低屈折率領域１３’やエアギャップ１４’を適用した場合について説明したが、本発明はこれに限らず、第４、５の実施形態について低屈折率領域１３’やエアギャップ１４’を適用することも勿論可能である。図２１及び図２２には、第４の実施形態について低屈折率領域１３’を適用した場合の上面図及び各断面図を示し、図２３及び図２４には、第５の実施形態について低屈折率領域１３’を適用した場合の上面図及び各断面図を示しておく。

【００４８】次に、本発明の第８の実施形態について説明する。図２５は、第８の実施形態に係る光方向性結合器の構成を示す上面図である。図２５において、本光方向性結合器は、従来の光方向性結合器について、光結合部の中央部分に、２つのコア１５間のギャップ幅をさらに狭くした強光結合領域を設けたものである。図では、従来の光方向性結合器の入出射部を第１、９領域とし、連結部を第２、８領域とし、光結合部を第３～７領域としている。光結合部となる第３～７領域は、従来と同様のギャップ幅Ｇ３を有する第３、７領域と、さらに狭いギャップ幅Ｇ４を有する強光結合領域としての第５領域と、第３、７領域と第５領域とをつなぐ第４、６領域とから構成されている。具体的な設定例としては、各コア１５の幅を７μｍ、高さを７μｍとし、第５領域におけるギャップ幅Ｇ４を４μｍとする。なお、光結合部に強光結合領域を設けたこと以外の構成は、従来の光方向性結合器の構成と同様である。

【００４９】このような構成の光方向性結合器では、強光結合領域を設けたことで、光結合部におけるギャップ幅がより狭くなるため結合長を短くできる。ただし、第３～７領域すべてにおけるギャップ幅を狭くすると、上述したように０次モードの電界分布の中央の窪みの極小値Ｉ１が大きくなって、光結合部における損失が増加してしまう。これを防ぐためには、光結合部の光入出射部分（第３、７領域）のギャップ幅を従来と同様に広くしておくことで、前記極小値Ｉ１を小さく維持でき損失の増加を防止できる。従って、第８の実施形態によれば、従来の光方向性結合器について、損失を増加させることなく小型化を図った光方向性結合器を実現できる。

【００５０】次に、本発明の第９の実施形態について説明する。図２６は、第９の実施形態に係る光方向性結合器の構成を示す上面図である。図２６において、本光方向性結合器は、上記第８の実施形態について、均一なコアサイズを有する各コア１５に代えて、少なくとも強光結合領域（第５領域）に位置する部分のコアサイズを小さくしたコア１５’を設けた構成とする。具体的には、強光結合領域における各コア１５’の幅を、例えば４μｍとしたものである。上記以外の構成は、第８の実施形態の構成と同様である。

【００５１】このような光方向性結合器では、上述の図３２に示したように、ギャップ幅及び比屈折率差Δが一定の状態であるならば、コアサイズの小さい方が結合長を短くすることができる。よって、第９の実施形態によれば、第８の実施形態と同様の効果が得られ、かつ、結合長をさらに短くできる。次に、本発明の第１０の実施

形態について説明する。

【００５２】図２７は、第１０の実施形態に係る光方向性結合器の構成を示す上面図である。また、図２８は、図２７の一点鎖線で示す(a) ～(e) における断面図である。図において、本光方向性結合器は、第８の実施形態の光方向性結合器について、第２の実施形態の場合と同様にして、少なくとも第３～７領域（光結合部）に位置する各コア間に低屈折率領域１６を設けた構成とする。低屈折率領域１６は、ここでは、第２領域の途中から第８領域の途中にかけて設けられ、その幅は強光結合領域におけるコア間のギャップ幅以下にしてある。なお、低屈折率領域１６の断面形状は、図２８(c) に示した形状に限らず、上述の図６(A) ～(D) などに示すような種々の形状とすることが可能である。また、ここで用いた低屈折率領域１６に代えて、第３の実施形態の場合と同様なエアギャップを設けるようにしてもよい。

【００５３】このような光方向性結合器では、低屈折率領域１６を設けたことによって、光結合部におけるコア間の屈折率が下がるため、クラッド１１とコア１５の比屈折率差Δを大きくすることができる。この場合の比屈折率差Δは、低屈折率領域１６の幅や深さ等を変えることで調節可能である。従って、第１０の実施形態によれば、結合長を一層短くできるとともに、光結合部における損失もより低くすることが可能である。

【００５４】なお、上記第１０の実施形態では、光結合部の各コアの間に低屈折率領域を設けるようにしたが、これ以外にも、上述した第６の実施形態の場合と同様に、各コアの間だけでなく各コアの外側にも低屈折率領域を設けるようにしてもよい。また、第９の実施形態の光方向性結合器について、低屈折率領域を設けるようにしても構わない。

【００５５】

【発明の効果】以上説明したように、本発明によれば、光結合が行われる第３領域におけるコアとクラッドとの比屈折率差が第１、５領域における比屈折率差よりも大きくなるようにしたことにより、結合長を短くできるため、高い結合効率で光ファイバとの接続を可能にしながら光方向性結合器の小型化を図ることが可能となる。また、各コアの屈折率を互いに略等しくしたり、低屈折率領域を設けたりなどすることによって、光結合の際の損失を低く抑えることができる。従って、低損失で小型の光方向性結合器を提供することができる。さらに、低屈折率領域を空気層で形成すれば、光方向性結合器の作製が簡易なものとなる。

【図面の簡単な説明】

【図１】本発明の第１の実施形態の構成を示す上面図である。

【図２】同上第１の実施形態の図１の(a) ～(e) における各断面図である。

【図３】同上第１の実施形態におけるダブルコア構造の形成方法の一例を説明する図である。

【図４】本発明の第２の実施形態の構成を示す上面図である。

【図５】同上第２の実施形態の図４の(a) ～(c) における各断面図である。

【図６】同上第２の実施形態の低屈折率領域の断面形状の例示図である。

【図７】本発明の第３の実施形態の構成を示す上面図である。

【図８】同上第３の実施形態の図７の(a) ～(c) における各断面図である。

【図９】同上第３の実施形態のエアギャップの断面形状の例示図である。

【図１０】本発明の第４の実施形態の構成を示す上面図である。

【図１１】同上第４の実施形態の図１０の(a) ～(c) における各断面図である。

【図１２】同上第４の実施形態に関して他の構成例を示す上面図である。

【図１３】本発明の第５の実施形態の構成を示す上面図である。

【図１４】同上第５の実施形態の図１３の(a) ～(e) における各断面図である。

【図１５】本発明の第６の実施形態の構成を示す上面図である。

【図１６】同上第６の実施形態の図１５の(a) ～(c) における各断面図である。

【図１７】同上第６の実施形態の低屈折率領域の断面形状の例示図である。

【図１８】本発明の第７の実施形態の構成を示す上面図である。

【図１９】同上第７の実施形態の図１８の(a) ～(c) における各断面図である。

【図２０】同上第７の実施形態のエアギャップの断面形状の例示図である。

【図２１】第６、７の実施形態に関して、第４の実施形態の構成に対して適用した場合の構成を示す上面図である。

【図２２】図２１の(a) ～(c) における各断面図である。

【図２３】第６、７の実施形態に関して、第５の実施形態の構成に対して適用した場合の構成を示す上面図である。

【図２４】図２３の(a) ～(c) における各断面図である。

【図２５】本発明の第８の実施形態の構成を示す上面図である。

【図２６】本発明の第９の実施形態の構成を示す上面図である。

【図２７】本発明の第１０の実施形態の構成を示す上面

図である。

【図２８】同上第１０の実施形態の図２７の(a)～(e)における各断面図である。

【図２９】従来の光方向性結合器の構成を示す上面図である。

【図３０】光ファイバとの結合効率と比屈折率差との関係を示す図である。

【図３１】コアサイズを一定とした場合の光結合部のギャップ幅に対する結合長の関係を示した図である。

【図３２】比屈折率差を一定とした場合の光結合部のギャップ幅に対する結合長の関係を示した図である。

【図３３】光結合部のギャップ幅に対する損失の関係を示した図である。

【図３４】光結合部における光パワーの移動の様子を説明する図である。

【図３５】損失を一定とした場合の比屈折率差に対する結合長の関係を示した図である。

【図３６】従来の導波型光スイッチの光結合部における電界強度分布を示す図である。

【符号の説明】

１０…シリコン基板

１１…クラッド

１２，１２’，１５，１５’…コア

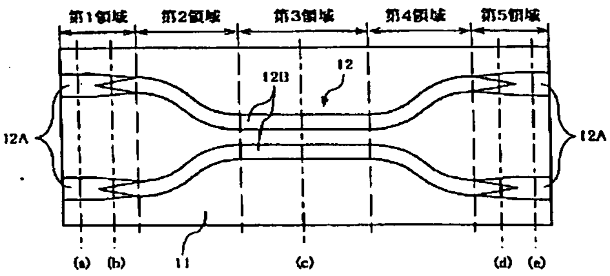
１２Ａ…アウターコア

１２Ｂ…インナーコア

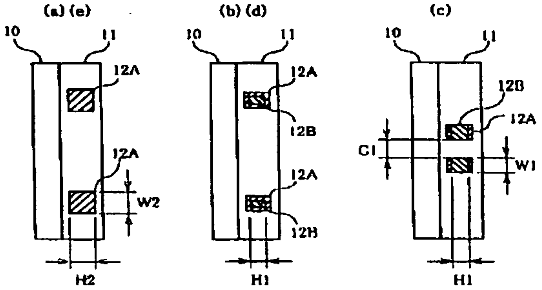
１３，１３’，１６…低屈折率領域

１４，１４’…エアギャップ

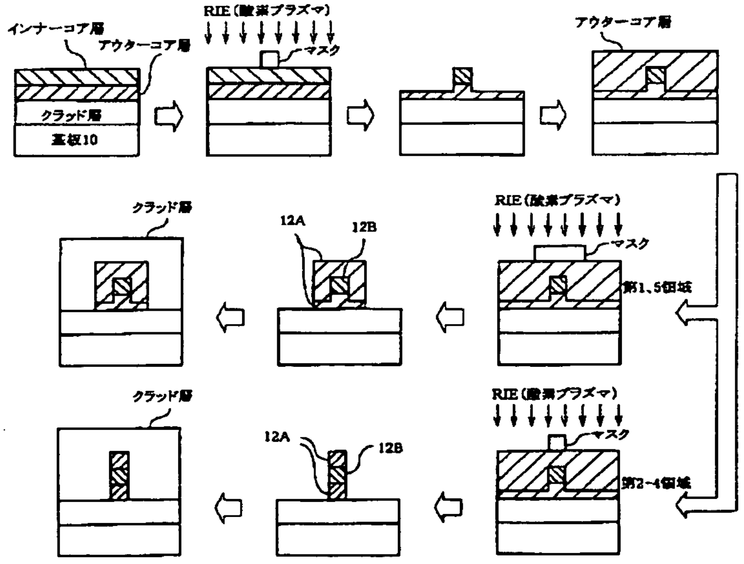
【図１】



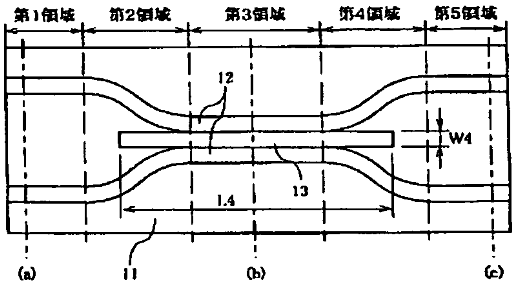
【図２】



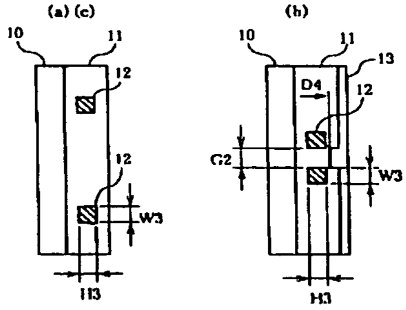
【図３】



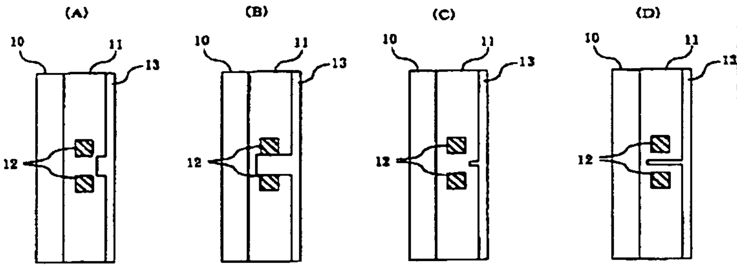
【図４】



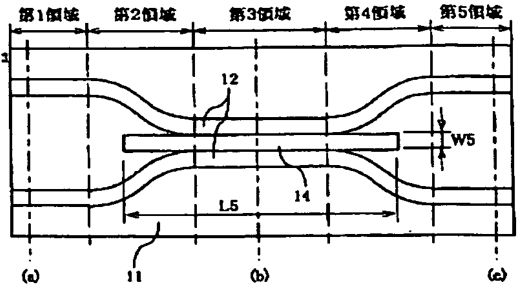
【図５】



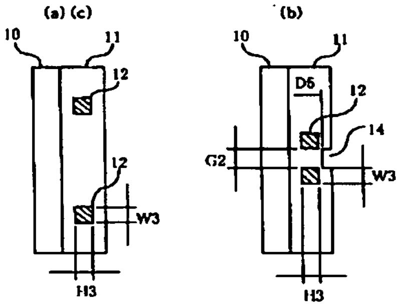
【図６】



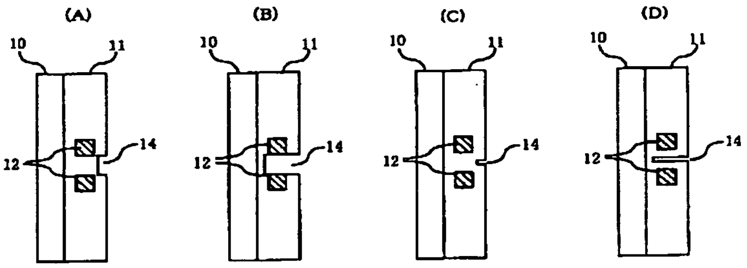
【図７】



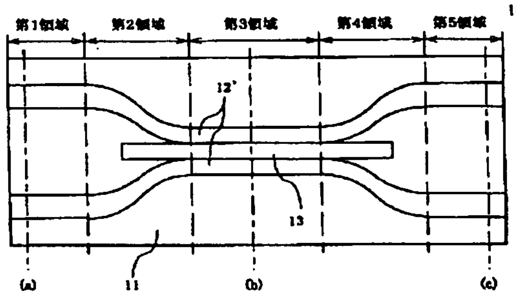
【図８】



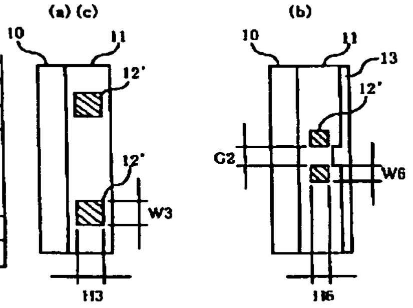
【図９】



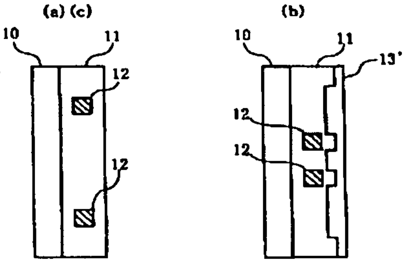
【図１０】



【図１１】



【図１６】



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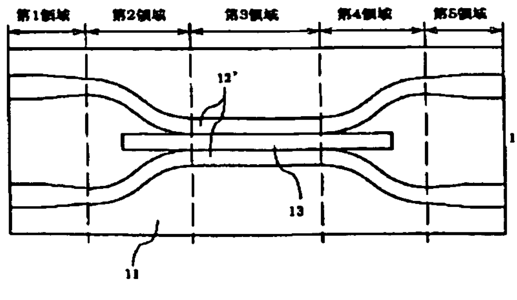

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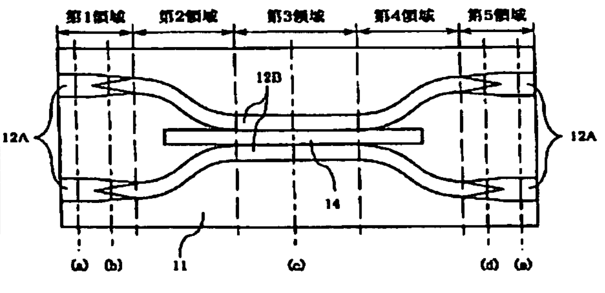

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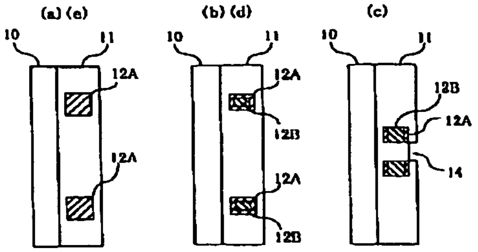

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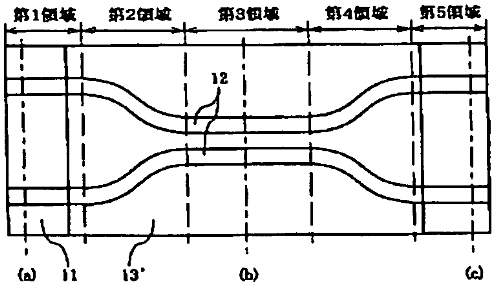

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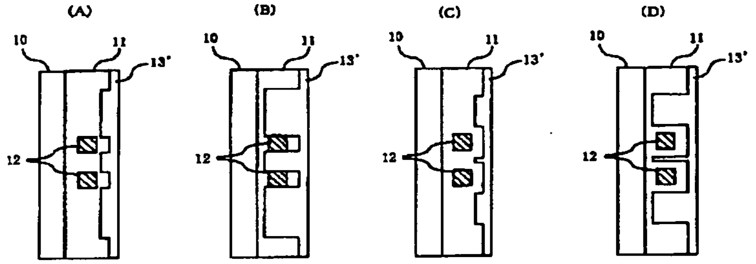

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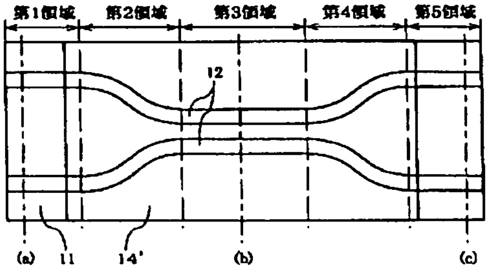

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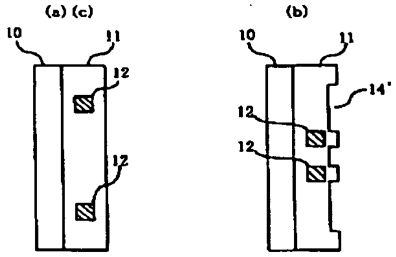

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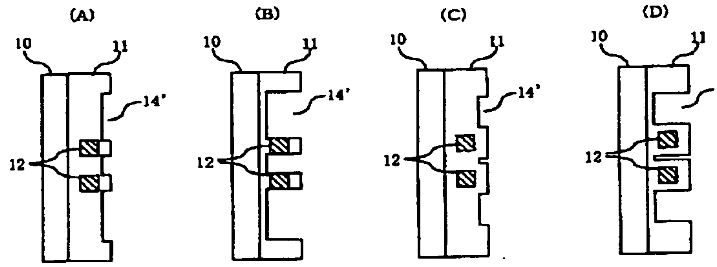

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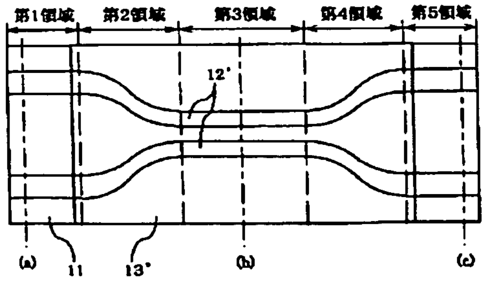

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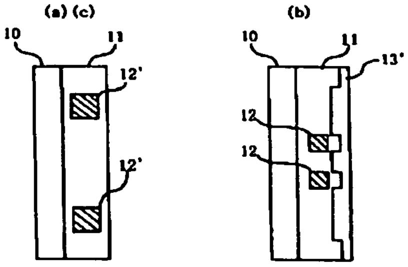

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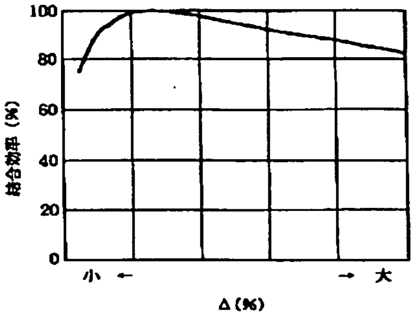

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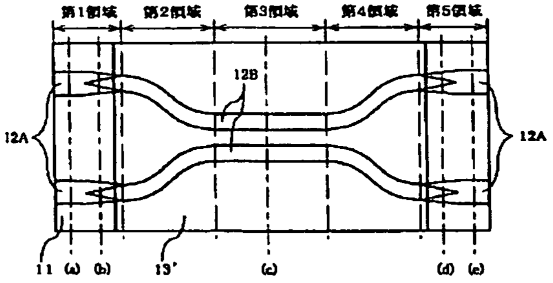

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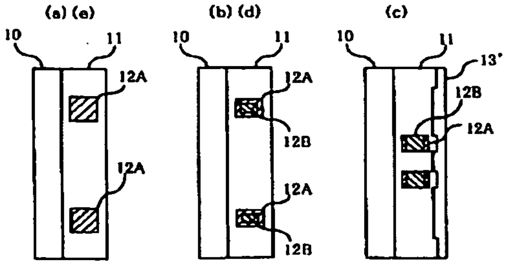

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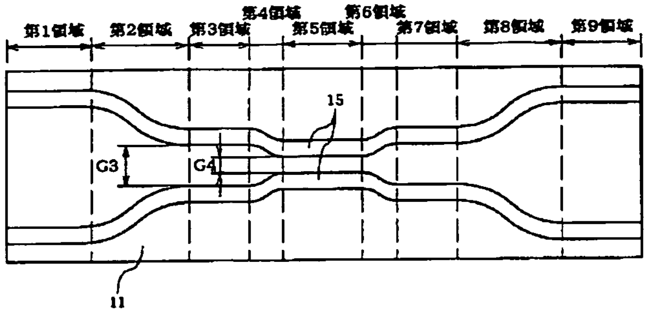

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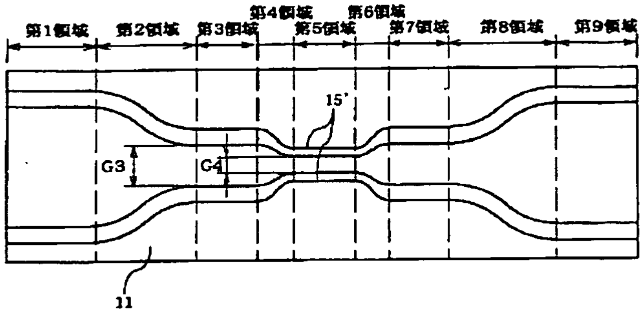

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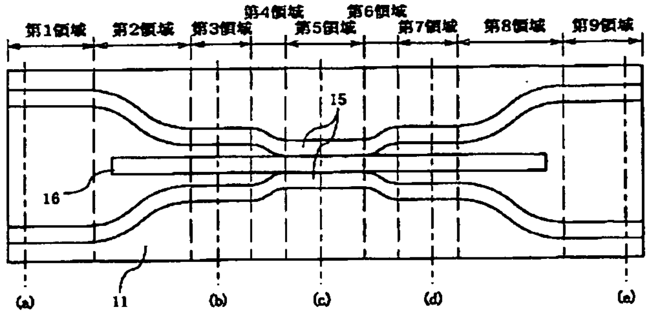

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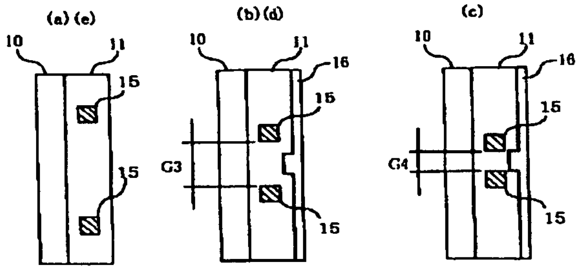

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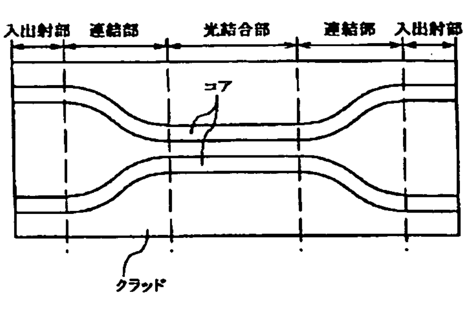

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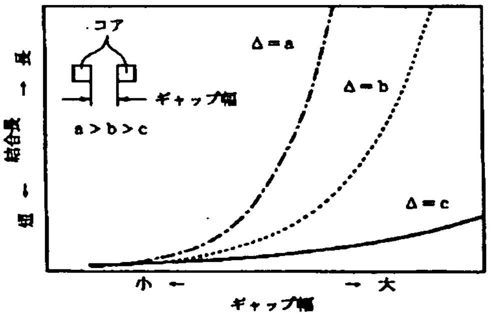

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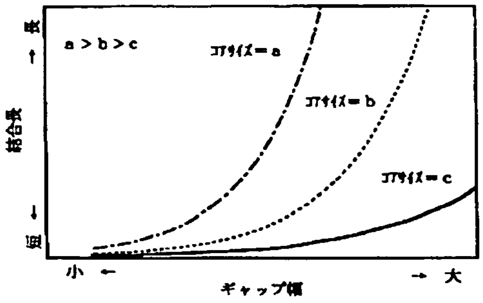

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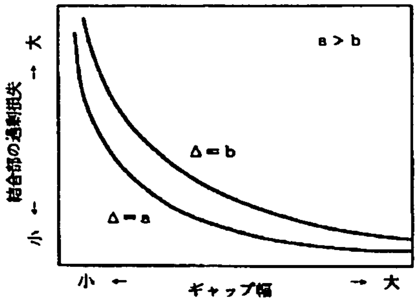

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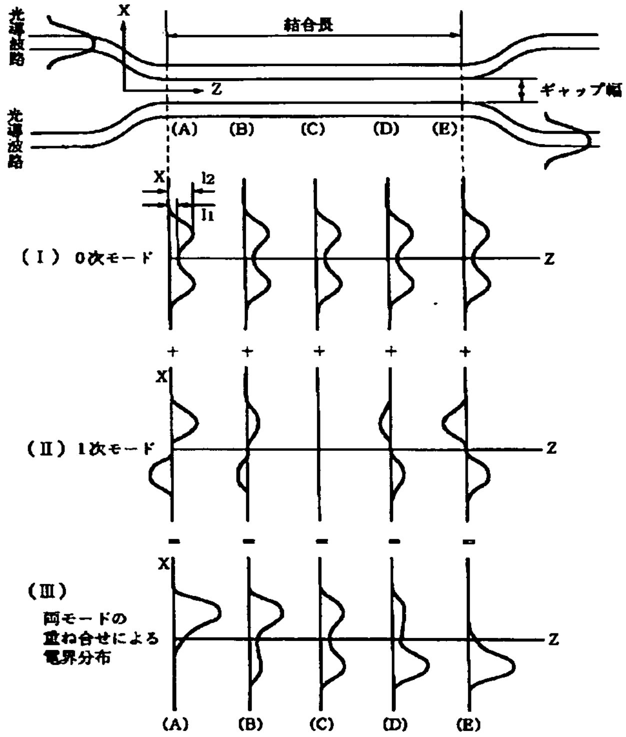

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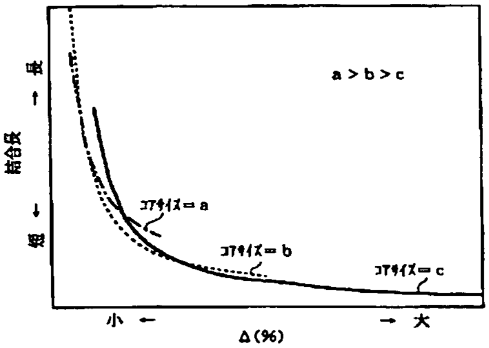

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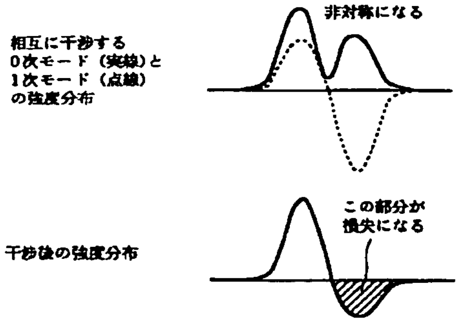

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3.In the drawings, any words are not translated.

CLAIMS

[Claim(s)]
[Claim 1] In the 1st field and the 5th field in which it has two optical waveguides continued and prepared in the 1-5th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3rd field Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 4th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively said each optical waveguide The optical directional coupler characterized by the relative index difference of the core and clad in the 3rd field being larger than the relative index difference of the core and clad in the 1st field and the 5th field at least.
[Claim 2] Said each optical waveguide is an optical directional coupler according to claim 1 to which the refractive index of the core in the 3rd field carries out abbreviation etc., is, and is mutually characterized by things at least.
[Claim 3] Said each optical waveguide is an optical directional coupler according to claim 1 or 2 to which core width of face of each of said optical waveguide which is equipped with the core of the double structure which consists of the inside core and the outside core which has a low refractive index relatively which has a high refractive index relatively, respectively, and is located in the 3rd field at least is characterized by considering as the width of face of said inside core, respectively.
[Claim 4] The optical directional coupler of any one publication of claim 1-3 characterized by having been prepared between the cores of each of said optical waveguide located in the 3rd field at least, having had the low refractive-index field with a low refractive index, and consisting of refractive indexes of a clad.
[Claim 5] The optical directional coupler according to claim 4 to which said low refractive-index field is characterized by what was formed of the air space.
[Claim 6] Said each optical waveguide is an optical directional coupler according to claim 4 or 5 characterized by the core width of face of the part in which said low refractive-index field is established being narrower than the core width of face of other parts.
[Claim 7] Said low refractive-index field is the optical directional coupler of any one publication of claim 4-6 characterized by being prepared between the cores of each of said optical waveguide located in the 3rd field at least, and in the outside of each core.
[Claim 8] In the 1st field and the 9th field in which it has two optical waveguides continued and prepared in the 1-9th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3-7th fields Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 8th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively

Spacing between said each optical waveguide located in the 5th field is made narrower than spacing between said each optical waveguide located in the 3rd field and the 7th field. The optical directional coupler characterized by each optical waveguide of the 5th field considering as the configuration connected with each optical waveguide of the 3rd field and the 7th field through the 4th field and the 6th field.
[Claim 9] Said each optical waveguide is an optical directional coupler according to claim 8 characterized by the width of face of the core located in the 5th field at least being narrower than the width of face of the core located in other fields.
[Claim 10] The optical directional coupler according to claim 8 or 9 characterized by having been prepared between the cores of each of said optical waveguide located in the 3-7th fields at least, having had the low refractive-index field with a low refractive index, and consisting of refractive indexes of a clad.

[Translation done.]

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the optical directional coupler of low loss about the optical directional coupler which uses optical waveguide by small [especially connectable with an optical fiber at high joint effectiveness].
[0002]
[Description of the Prior Art] Generally, the optical directional coupler constituted using optical waveguide is an optical device for branching of light and making multiplexing, modification of a propagation path, etc., for example, is used for the wavelength filter of an optical waveguide mold, the element components of an interferometer, etc. As shown in drawing 29 , there are some which have the connection section which connects the optical coupling section which has arranged two cores of optical waveguide in parallel at narrow spacing, the close outgoing radiation section by which the core has been arranged at comparatively large spacing, and the optical coupling section and the close outgoing radiation section in the conventional optical directional coupler. In this conventional directional coupler, the configuration of a core cross section perpendicular to the travelling direction of light is the same about each of the close outgoing radiation section, the optical coupling section, and the connection section, and the relative index difference of a core and a clad is the same.
[0003] In the optical directional coupler of the above structures, if it is going to raise joint effectiveness with the single mode fiber whose mode size of the light guided is about 10 micrometers, it is necessary to bring the core size and relative index difference of optical waveguide which constitute an optical directional coupler close to the core size and relative index difference of a single mode fiber.
[0004]
[Problem(s) to be Solved by the Invention] However, in the conventional optical directional coupler, if it is going to make an optical directional coupler into low loss when the core size and relative index difference of optical waveguide are brought close to a single mode fiber, since it will be necessary to lengthen the optical coupling section, there was a problem that an optical directional coupler will be enlarged.
[0005] Here, relation with the core size of optical waveguide, and the relative index difference and the die length of the optical coupling section which constitutes an optical directional coupler is explained briefly. First, they are the refractive index n1 of a core, and the refractive index n2 of a clad about the relative index difference delta of a core and a clad. It uses and a definition is given as follows.
delta= (n1-n2) / n2 -- (1)
If the joint effectiveness of optical waveguide and an optical fiber becomes the highest when the relative index difference delta of optical waveguide serves as a value comparable as the relative index difference of an optical fiber, as shown in drawing 30 , and relative index difference delta becomes large rather than the value, joint effectiveness will fall. Moreover, although not illustrated, if joint effectiveness becomes the highest at the time of a value comparable as the core diameter of an optical fiber and the core size of optical waveguide becomes small rather than the core diameter of an optical fiber about the

core size of optical waveguide, joint effectiveness will fall.
[0006] As constraint for making optical waveguide into single mode waveguide about the relative index difference delta of an optical directional coupler, and the magnitude of a core, it may be said that magnitude of a core must be made small, so that relative index difference delta is enlarged. Drawing 31 and drawing 32 show bond length's relation to the gap width of face (spacing of two cores) of the optical coupling section of an optical directional coupler. However, core size (magnitude of one side when making a core into a square) is set constant, the relation when changing relative index difference delta is shown in drawing 31 , relative index difference delta is set constant and the relation when changing core size is shown in drawing 32 . With bond length, it considers as the shortest die length to which the optical power which carries out KOAHE migration in another side becomes 100% from one core here.
[0007] Bond length becomes short, so that gap width of face is small if core size and relative index difference delta are fixed as shown in drawing, and bond length becomes short, so that relative index difference delta is small, if core size and gap width of face are fixed. Moreover, bond length becomes short, so that core size will become small, if relative index difference delta and gap width of face are fixed. Drawing 33 shows the relation of loss of the optical coupling section to the gap width of face of the optical coupling section of an optical directional coupler according to relative index difference delta. However, core size is fixed.
[0008] If its attention is paid to the loss in the optical coupling section as shown in drawing 33 , loss becomes small, so that gap width of face is large, if relative index difference delta is fixed, and loss will become small, so that relative index difference delta is large, if gap width of face is fixed. This reason is explained as follows. As shown in drawing 34 , migration of the optical power in the optical coupling section of an optical directional coupler is produced by association with zero-order mode and the primary mode. That is, in case the single-mode light inputted from the left end of the optical waveguide of the top of the two optical waveguides shown in the upper case of drawing 34 spreads the optical-coupling section, it will come to have electric-field distribution in zero-order mode as shown in drawing 34 (I), and electric-field distribution in the primary mode as shown in drawing 34 (II), and the electric-field distribution by the superposition in both the modes as shown in drawing 34 (III) will produce it.
[0009] Under the present circumstances, in order that the mode configuration when adding the two modes may approach the mode configuration by which a guided wave is carried out to optical waveguide of one of the two so that the minimal value (this is set to I1) of the hollow of the central part of electric-field distribution in the zero-order mode in the incidence section (A) of the optical coupling section and the outgoing radiation section (E) is small, loss becomes small at the optical coupling section. On the contrary, if the minimal value I1 of a hollow is large, since the mode configuration when adding the two modes in order not to separate on two crests where electric-field distribution in zero-order mode is beautiful will not turn into a mode configuration by which a guided wave is carried out to optical waveguide of one of the two (the component by which a guided wave is carried out in the optical waveguide of another side increases), only in the part, loss becomes large.
[0010] The minimal value I1 of the hollow of the central part in zero-order mode has the relation of becoming so small that gap width of face being large if core size and relative index difference delta are fixed, and becoming so small that core size being large if relative index difference delta and gap width of face are fixed, and becoming so small that relative index difference delta being large if gap width of face and core size are fixed. Drawing 35 sets peak intensity in zero-order mode to I0, and the relation of relative index difference delta and bond length in case I1/I0 becomes fixed (namely, when loss becomes fixed) is shown according to core size. As shown in drawing 35 , even if core size is large and it is small, it turns out that bond length becomes short, so that relative index difference delta is enlarged.
[0011] Therefore, it is small, and as one means to realize the optical directional coupler of low loss, relative index difference delta of a core and a clad is enlarged, and it is thought effective to adjust core size according to it. As an optical device of the directivity joint mold which gave the description to refractive-index distribution of optical waveguide, the guided wave mold optical switch indicated by JP,4-19713,A etc., for example is well-known. This guided wave mold optical switch is enlarging the refractive-index difference of two approaching optical waveguides, namely, giving a difference to the

refractive index of each core of the optical waveguide located in the optical coupling section, and tends to enlarge the difference of the propagation constant (velocity of propagation) in zero-order mode and the primary mode.

[0012] However, in the above-mentioned guided wave mold optical switch, since field strength distribution in the zero-order mode in the optical coupling section and the primary mode becomes unsymmetrical in two optical waveguides as shown in drawing 36 , the field strength distribution after interference does not become a single crest. For this reason, when the above well-known techniques are applied to the optical directional coupler of refractive-index immobilization, problems, such as an increment in loss and a fall of an extinction ratio, will arise.

[0013] This invention was made paying attention to the above-mentioned point, and it is small and it aims at the thing which can connect with an optical fiber at high joint effectiveness and for which the optical directional coupler of low loss is offered.

[0014]

[Means for Solving the Problem] for this reason, in the 1st field and the 5th field in which the optical directional coupler of this invention has two optical waveguides continued and prepared in the 1-5th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3rd field Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 4th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively, the relative index difference of the core and clad in the 3rd field makes said each optical waveguide at least larger than the relative index difference of the core and clad in the 1st field and the 5th field.

[0015] According to this configuration, the light by which incidence was carried out to one optical waveguide of the 1st field spreads to the 3rd field through the 2nd field, for example. In the 3rd field, since two optical waveguides are approaching, the light which has spread one optical waveguide is outputted from the optical waveguide of another side, and spreads to the 5th field through the 4th field. Under the present circumstances, the die length of the 3rd field, i.e., bond length, becomes short by relative index difference of the 3rd field where optical coupling is performed being made larger than the 1st field and the 5th field. Moreover, since the relative index difference of the 1st field and the 5th field is small, it becomes connectable with an optical fiber at high joint effectiveness.

[0016] Moreover, as for said each optical waveguide, it is desirable to make it become [on which the refractive index of the core in the 3rd field spreads abbreviation etc. mutually at least]. the refractive index of each core of two optical waveguides -- abbreviation -- by making it equal, since the field strength in the zero-order mode in each optical waveguide of the 3rd field and the primary mode serves as symmetrical distribution, the field strength distribution after interference serves as a single crest mostly, and the loss in the case of optical coupling becomes low.

[0017] Furthermore, it has the core of the double structure which consists of the inside core and the outside core which has a low refractive index relatively which has a high refractive index relatively as a concrete configuration of each of said optical waveguide, respectively, and the core width of face of each of said optical waveguide located in the 3rd field at least may be made to be made into the width of face of said inside core, respectively. In addition, about the above-mentioned optical directional coupler, it is desirable to be prepared between the cores of each of said optical waveguide located in the 3rd field at least, to have a low refractive-index field with a low refractive index, and to consist of refractive indexes of a clad. This low refractive-index field may be formed by the air space. Thus, while the relative index difference of the 3rd field becomes larger and bond length becomes short by preparing a low refractive-index field, the refractive index between the cores of the optical coupling section becomes low, and loss becomes small.

[0018] Moreover, as for said each optical waveguide, it is desirable to make it the core width of face of the part in which said low refractive-index field is established become narrower than the core width of face of other parts. Thereby, optical coupling section core size becomes small, and bond length becomes still shorter. Furthermore, said low refractive-index field may be made to establish between the cores of each of said optical waveguide located in the 3rd field at least, and in the outside of each core. By doing in this way, the relative index difference of the core in the 3rd field and a clad becomes still larger.

[0019] moreover, in the 1st field and the 9th field in which other optical directional couplers concerning this invention have two optical waveguides continued and prepared in the 1-9th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3-7th fields Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 8th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively Spacing between said each optical waveguide located in the 5th field is made narrower than spacing between said each optical waveguide located in the 3rd field and the 7th field, and each optical waveguide of the 5th field considers as the configuration connected with each optical waveguide of the 3rd field and the 7th field through the 4th field and the 6th field.

[0020] Since spacing between each core of the 3rd and 7 field is larger than core spacing of the 5th field while bond length becomes short according to this configuration, since the 5th field located in the central part of the 3-7th fields used as the optical coupling section turns into a strong optical coupling field, the loss in the optical coupling section comes to be suppressed low. Furthermore, you may make it said each optical waveguide become narrower than the width of face of the core to which the width of face of the core located in the 5th field at least is located in other fields. In addition, about the above-mentioned optical directional coupler, it is desirable to be prepared between the cores of each of said optical waveguide located in the 3-7th fields at least, to have a low refractive-index field with a low refractive index, and to consist of refractive indexes of a clad.

[0021]

[Embodiment of the Invention] Hereafter, the operation gestalt of this invention is explained based on a drawing. Drawing 1 is the plan showing the configuration of the optical directional coupler concerning the 1st operation gestalt. Moreover, drawing 2 is (a) shown with the alternate long and short dash line of drawing 1 . - (e) It is the sectional view which can be set. In drawing, this optical directional coupler consists of optical waveguide layers which used polyimide etc. and were formed for example, on the silicon substrate 10 and this silicon substrate 10. An optical waveguide layer consists of two cores 12 surrounded by the clad 11, each core 12 is formed in parallel with a longitudinal direction by drawing 1 , and mutual spacing is narrow in the central part. Here, the part (close outgoing radiation section) located in a right-and-left edge by drawing 1 is made into the 1st field and the 5th field, make into the 3rd field the part (optical coupling section) to which spacing of each core 12 located in the center became narrow, and let the parts (connection section) located between the 1st field and the 5th field, and the 3rd field be the 2nd field and the 4th field.

[0022] Each core 12 has the double core fabric which consists of core (inner core) 12B located in core (outer core) 12A and the inside which are located outside. Outer core 12A is formed near the edge of the 1st field where connection with a single mode fiber etc. is made, and the 5th field (refer to drawing 2 (a) and (e)), and becomes connectable with a single mode fiber at high joint effectiveness by having the large cross-sectional area in a connection end face. The cross section is made narrower than outer core 12A, and it is formed in the 2nd field - the 4th field, applying inner core 12B. moreover, the refractive index of the part which two cores 12 counter -- mutual -- abbreviation -- it is made to become equal, and it is set up so that two cores 12 may have symmetrical structure.

[0023] Conversion to inner core 12B from outer core 12A is performed by joining each core formed in the shape of a taper in the 1st field and the 5th field. The core cross section of this conversion part serves as double structure, as shown in drawing 2 (b) and (d). In addition, although it was made to perform conversion to inner core 12B from outer core 12A in the 1st field and the 5th field, it may be made to carry out not only this but in the 2nd field and the 4th field. However, if it changes in the 1st field and the 5th field, since the core of the 2nd field and the 4th field can be made thin and radius of curvature

can be made small, an optical directional coupler will become smaller.
[0024] The refractive index (n1o) of outer core 12A is higher than the refractive index (n2) of a clad 11, and the refractive index (n1i) of inner core 12B is made higher than the refractive index (n1o) of outer core 12A. That is, the refractive index of optical waveguide is set up so that it may have the following size relation.
n1 i>n1 o>n2 -- here shows the example of each set point in the 1st operation gestalt. Core size is set to width-of-face W1=4micrometerx height H1=7micrometer about inner core 12B, and it is refractive-index n1i 1.532 It carries out. Core size is set to width-of-face W2=7micrometerx height H2=7micrometer about outer core 12A, and it is refractive-index n1o 1.528 It carries out. About a clad 11, it is a refractive index n2. 1.520 It carries out and thickness of 10 micrometers and an exaggerated clad is set to 15 micrometers for the thickness of an undershirt clad. Moreover, by such setup, it is the gap width of face G1 between the cores in the 3rd field 5.5 Bond length will be set to 5.4 mm if mum.
[0025] Moreover, the formation approach of the double core fabric mentioned above is explained briefly. Drawing 3 is the formation approach of a double core fabric of having used for example, fluorination polyimide. In addition, although fluorination polyimide was used here, this invention is not restricted to this. However, if an organic material like fluorination polyimide is used, a double core fabric can be produced comparatively easily.
[0026] In drawing 3 , sequential formation of a cladding layer, an outer core layer, and the inner core layer is first carried out by the spin coat on a silicon substrate 10. Next, after forming the mask equivalent to inner core width of face on an inner core layer, a part of inner core layer and outer core layer are etched by reactive ion etching (RIE), and an outer core layer is further applied so that an inner core may be surrounded.
[0027] Next, in forming the double core part located in the 1st field or the 5th field, after forming the mask equivalent to outer core width of face on an outer core layer, RIE removes an unnecessary outer core layer, an outer core is formed, a cladding layer is applied so that an outer core may be surrounded further, and the double core fabric of the 1st field or the 5th field is formed. In forming the core part located in the 2nd - the 4th field, after, forming the mask equivalent to inner core width of face on an outer core layer on the other hand, RIE removes an unnecessary outer core layer. However, an outer core will remain in the upper and lower sides of an inner core in this case. And a cladding layer is applied so that a core may be surrounded, and the double core fabric of the 2nd - the 4th field is formed.
[0028] In the optical directional coupler which has the double core fabric formed as mentioned above, in connection with a single mode fiber, since it connects with outer core 12A with big core size, joint effectiveness higher than the conventional optical directional coupler is realized. On the other hand, in the optical coupling section of the 3rd field, since inner core 12B which made the refractive index high is formed and the relative index difference delta of a clad 11 and a core 12 is large, bond length (the die length of the 3rd field) can be shortened. In the conventional optical directional coupler (for example, core width of face is 7 micrometers, and relative index difference delta is 0.5 etc.) which does not specifically have the inner core which made the refractive index high, although bond length is set to about 10mm, bond length becomes 5.4 mm extent by using the structure of this operation gestalt. Therefore, a small optical directional coupler is comparatively realizable by low loss. Moreover, in the optical coupling section, by making width of face of a core 12 into inner core width of face, and adjusting a setup of this width of face suitably, even if relative index difference delta becomes large, it is possible to maintain a single mode.
[0029] Next, the 2nd operation gestalt of this invention is explained. Drawing 4 is the plan showing the configuration of the optical directional coupler concerning the 2nd operation gestalt. Moreover, drawing 5 is (a) shown with the alternate long and short dash line of drawing 4 . - (c) It is the sectional view which can be set. In drawing, this optical directional coupler is taken as the configuration which formed the low refractive-index field 13 between each core located in the 3rd field (optical coupling section) at least, in order to form two cores 12 surrounded by the clad 11 on the silicon substrate 10 and to enlarge relative index difference delta of the clad 11 and core 12.
[0030] Unlike the case of the 1st operation gestalt, each core 12 shall have single core size and a single

refractive index (n1). When an example is shown, core size is set to width-of-face W3=7micrometerx height H3=7micrometer, and it is a refractive index n1. 1.530 It carries out. Moreover, it is the gap width of face G2 between each core 5.5 It is referred to as mum. Furthermore, about a clad 11, it is the refractive index n2 1.522 It carries out.

[0031] The low refractive-index field 13 has the width of face below the gap width of face between each core 12 in the 3rd field, and is the refractive index n2 of a clad 11. Low refractive index n3 It is the field which it has. the optical directional coupler for which this low refractive-index field 13 used polyimide -- etching -- a slot -- forming -- there -- a clad 11 -- low -- if the refractive index matter is applied, it can form. the cross-section configuration of the low refractive-index field 13 -- for example, drawing 6 (A) - (D) etc. -- considering as various configurations as shown is possible. Here, as a concrete example of a setting of the low refractive-index field 13, it is referred to as width-of-face W4=4micrometerx depth D4=4micrometerx die-length L4=6000micrometer, and is a refractive index n3. 1.520 It carries out.

[0032] According to the optical directional coupler of the above structures, since relative index difference delta in the optical coupling section can be enlarged, bond length can be shortened. Moreover, relative index difference delta is the width of face, the depth, and the refractive index n3 of the low refractive-index field 13. It can adjust by changing. Furthermore, from the refractive index between the cores in the optical coupling section falling, since the minimal value Il of the hollow of the central part of electric-field distribution in the zero-order mode shown in above-mentioned drawing 34 (I) becomes low, loss in the optical coupling section can be made low. Therefore, according to the 2nd operation gestalt, it can connect with a single mode fiber at high joint effectiveness like the case of the 1st operation gestalt, and a small optical directional coupler can be realized by low loss.

[0033] Next, the 3rd operation gestalt of this invention is explained. Drawing 7 is the plan showing the configuration of the optical directional coupler concerning the 3rd operation gestalt. Moreover, drawing 8 is (a) shown with the alternate long and short dash line of drawing 7 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, this optical directional coupler replaces with the low refractive-index field 13, and forms an air gap (air space) 14. Configurations other than the above are the same as the configuration of the 2nd operation gestalt.

[0034] If an air gap 14 is the optical waveguide which used a quartz system and fluorination polyimide, it is simply producible by etching. moreover, the case of the cross-section configuration of the low refractive-index field 13 which mentioned above the cross-section configuration of an air gap 14 -- the same -- for example, drawing 9 (A) - (D) etc. -- considering as various configurations as shown is possible. Here, a width-of-face W5=4micrometerx depth D5=4micrometerx die-length L5=6000micrometer thing is used as an example of an air gap 14.

[0035] According to the optical directional coupler of the above structures, like the case of the 2nd operation gestalt, since relative index difference delta in the optical coupling section can be enlarged, bond length can be shortened. Moreover, relative index difference delta can be adjusted by changing the width of face and the depth of an air gap 14. Furthermore, since the refractive index between the cores in the optical coupling section falls, loss in the optical coupling section can also be made low. In addition, an air gap 14 also has the advantage that it can form easily compared with the low refractive-index field 13.

[0036] Next, the 4th operation gestalt of this invention is explained. Drawing 10 is the plan showing the configuration of the optical directional coupler concerning the 4th operation gestalt. Moreover, drawing 11 is (a) shown with the alternate long and short dash line of drawing 10 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, core size covers an overall length, and this optical directional coupler is replaced with two uniform cores 12, and prepares two core 12' which made smaller than the part located in other fields core size of the part located in the 3rd field. Configurations other than the above are the same as the configuration of the 2nd operation gestalt.

[0037] Each core 12' about the part located in the 1st field and the 5th field The size of the part which has the same size as the core 12 used with the 2nd operation gestalt, and is located in the 3rd part For example, it was referred to as width-of-face W6=4micrometerx height H6=4micrometer, and the part located in the 2nd field and the 4th field was formed in the shape of a taper, and has connected the 3rd field, the 1st field, and the 5th field. Moreover, refractive index n1 of the core in each field It is set up so that it may become equal, for example, it is refractive-index n1 =1.530. It is carried out. The relative index difference delta at the time of using this core 12' can be adjusted by changing width of face, the depth, etc. of the low refractive-index field 13.

[0038] According to this configuration, optical waveguide will become a multimode if core size becomes [relative index difference delta] large in a fixed case. In single mode ******, relative index difference delta can be enlarged, so that core size is made small. If relative index difference delta is enlarged and core size is made small as shown in above-mentioned drawing 35 , bond length can be shortened with a single mode maintained. Therefore, according to the above-mentioned configuration, a smaller optical directional coupler will be realized more by low loss. Moreover, in the part located in the 1st field and the 5th field, joint effectiveness with a single mode fiber is highly maintained for core size by that in the size case.

[0039] In addition, although it was made to make thin the core of the part located in the 3rd field with the 4th operation gestalt mentioned above, as shown in drawing 12 , not only the optical coupling section but the core of the part located in the 2nd field and the 4th field may be made thin. If it does in this way, since the curvature for a bend section of the 2nd field and the 4th field can be made small, an optical directional coupler can be made still smaller. Moreover, the low refractive-index field 13 of the 4th above-mentioned operation gestalt may be replaced with an air gap 14 like the case of the 3rd operation gestalt.

[0040] Next, the 5th operation gestalt of this invention is explained. Drawing 13 is the plan showing the configuration of the optical directional coupler concerning the 5th operation gestalt. Moreover, drawing 14 is (a) shown with the alternate long and short dash line of drawing 13 . - (e) It is the sectional view which can be set. In drawing, like the case of the 3rd operation gestalt, this optical directional coupler forms an air gap 14 between each core of the 3rd field at least, and enlarges relative index difference delta of a clad 11 and core 12B about the optical directional coupler of the double core fabric of the 1st operation gestalt mentioned above. In addition, the air gap 14 used here can also be made into the same low refractive-index field 13 as the case of the 2nd operation gestalt mentioned above.

[0041] In the optical directional coupler of such a configuration, since relative index difference delta in the optical coupling section can be enlarged by having considered as the double core fabric, without lowering joint effectiveness with a single mode fiber, bond length can be shortened further. Moreover, since the minimal value Il of the hollow of the central part in the zero-order mode mentioned above can be made low by having formed the air gap 14, loss in the optical coupling section can be made low.

[0042] Next, the 6th operation gestalt of this invention is explained. Drawing 15 is the plan showing the configuration of the optical directional coupler concerning the 6th operation gestalt. Moreover, drawing 16 is (a) shown with the alternate long and short dash line of drawing 15 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, this optical directional coupler prepares low refractive-index field 13' not only in between each core 12 but in the outside of each core 12 in the 3rd field at least, in order to enlarge more relative index difference delta of a clad 11 and a core 12. Other configurations are the same as the configuration of the 2nd operation gestalt.

[0043] Low refractive-index field 13' is continued and formed near the boundary of the 4th and 5 field from near the boundary of the 1st and 2 field here, and the cross-section configuration is drawing 16 (b). It has the part projected between two cores 12 and on the outside of each core 12 so that it may be shown. in addition, the cross-section configuration of low refractive-index field 13' -- drawing 17 (A) - (D) etc. -- considering as various configurations as shown is possible. It is possible to adjust suitably the relative index difference delta of a clad 11 and a core 12 by changing width of face, the depth, etc. of this low refractive-index field 13'.

[0044] In the optical directional coupler of such a configuration, since the relative index difference delta in the optical coupling section becomes still larger compared with the case of the 2nd operation gestalt, it is possible to shorten bond length more. Moreover, like the case of the 2nd operation gestalt, since the refractive index between each core 12 falls, the minimal value Il of the hollow of the center in zero-order mode becomes small, and serves as low loss. Therefore, according to the 6th operation gestalt, it is more small and the optical directional coupler of low loss can be realized.

[0045] Next, the 7th operation gestalt of this invention is explained. Drawing 18 is the plan showing the configuration of the optical directional coupler concerning the 7th operation gestalt. Moreover, drawing 19 is (a) shown with the alternate long and short dash line of drawing 18 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 6th operation gestalt, this optical directional coupler replaces with low refractive-index field 13', and prepares air gap (air space) 14'. This configuration is the same as that also of what replaced with air gap 14' the air gap 14 used with the 3rd operation gestalt. Configurations other than the above are the same as the configuration of the 6th operation gestalt.

[0046] If this air gap 14' is the optical waveguide which used a quartz system and fluorination polyimide, it is simply producible by etching. moreover, the case of the cross-section configuration of low refractive-index field 13' which mentioned above the cross-section configuration of air gap 14' -- the same -- for example, drawing 20 (A) - (D) etc. -- considering as various configurations as shown is possible. It is possible to adjust suitably the relative index difference delta of a clad 11 and a core 12 by changing width of face, the depth, etc. of this air gap 14'.

[0047] According to the optical directional coupler of the above structures, like the case of the 6th operation gestalt, since the relative index difference delta in the optical coupling section becomes still larger, bond length can be shortened more and loss in the optical coupling section can also be made low. Furthermore, air gap 14' also has the advantage that it can form easily compared with low refractive-index field 13'. In addition, although the above-mentioned 6th and the operation gestalt of 7 explained the case where low refractive-index field 13' and air gap 14' were applied about the operation gestalt of the 2nd and 3, not only this but, of course, this invention can apply low refractive-index field 13' and air gap 14' about the operation gestalt of the 4th and 5. In drawing 21 and drawing 22 , the plan and each sectional view at the time of applying low refractive-index field 13' are shown about the 4th operation gestalt, and the plan and each sectional view at the time of applying low refractive-index field 13' about the 5th operation gestalt are shown in drawing 23 and drawing 24 at them.

[0048] Next, the 8th operation gestalt of this invention is explained. Drawing 25 is the plan showing the configuration of the optical directional coupler concerning the 8th operation gestalt. In drawing 25 , this optical directional coupler establishes the strong optical coupling field which made still narrower gap width of face between two cores 15 in the central part of the optical coupling section about the conventional optical directional coupler. In drawing, the close outgoing radiation section of the conventional optical directional coupler is made into the 1st and 9 field, the connection section is made into the 2nd and 8 field, and the optical coupling section is made into the 3-7th fields. The 3-7th fields used as the optical coupling section consist of the 4th and 6 fields which connect the 3rd and 7 field which has the same gap width-of-face G3 as usual, the 5th field as a strong optical coupling field which has the still narrower gap width of face G4, and the 3rd and 7 field and the 5th field. As a concrete example of a setting, width of face of each core 15 is set to 7 micrometers, height is set to 7 micrometers, and gap width of face G4 in the 5th field is set to 4 micrometers. In addition, the configuration except having established the strong optical coupling field in the optical coupling section is the same as the configuration of the conventional optical directional coupler.

[0049] In the optical directional coupler of such a configuration, since the gap width of face in the optical coupling section becomes narrower by having prepared the strong optical coupling field, bond length can be shortened. However, if gap width of face in all the 3-7th fields is narrowed, as mentioned above, the minimal value Il of the hollow of the center of electric-field distribution in zero-order mode will become large, and the loss in the optical coupling section will increase. In order to prevent this, by making large gap width of face of the optical ON outgoing radiation part (the 3rd and 7 field) of the optical coupling section as usual, said minimal value Il can be maintained small and the increment in loss can be prevented. Therefore, according to the 8th operation gestalt, the optical directional coupler aiming at a miniaturization can be realized about the conventional optical directional coupler, without making loss increase.

[0050] Next, the 9th operation gestalt of this invention is explained. Drawing 26 is the plan showing the configuration of the optical directional coupler concerning the 9th operation gestalt. In drawing 26 , this optical directional coupler is replaced with each core 15 which has uniform core size about the operation gestalt of the above 8th, and is taken as the configuration which prepared core 15' which made small core size of the part located in a strong optical coupling field (the 5th field) at least. Specifically, width of face of each core 15' in a strong optical coupling field is set to 4 micrometers. Configurations other than the above are the same as the configuration of the 8th operation gestalt.

[0051] In such an optical directional coupler, if gap width of face and relative index difference delta are in a fixed condition as shown in above-mentioned drawing 32 , the one where core size is smaller can shorten bond length. Therefore, according to the 9th operation gestalt, the same effectiveness as the 8th operation gestalt is acquired, and bond length can be shortened further. Next, the 10th operation gestalt of this invention is explained.

[0052] Drawing 27 is the plan showing the configuration of the optical directional coupler concerning the 10th operation gestalt. Moreover, drawing 28 is (a) shown with the alternate long and short dash line of drawing 27 . - (e) It is the sectional view which can be set. In drawing, this optical directional coupler is taken as the configuration which formed the low refractive-index field 16 between each core located in the 3-7th fields (optical coupling section) at least like the case of the 2nd operation gestalt about the optical directional coupler of the 8th operation gestalt. It is prepared applying the low refractive-index field 16 in the middle of the 8th field from the middle of the 2nd field here, and the width of face is made below into the gap width of face between the cores in a strong optical coupling field. in addition, the cross-section configuration of the low refractive-index field 16 -- drawing 28 (c) Not only the shown configuration but above-mentioned drawing 6 (A) - (D) etc. -- considering as various configurations as shown is possible. Moreover, it replaces with the low refractive-index field 16 used here, and you may make it prepare the same air gap as the case of the 3rd operation gestalt.

[0053] In such an optical directional coupler, since the refractive index between the cores in the optical coupling section falls by having formed the low refractive-index field 16, relative index difference delta of a clad 11 and a core 15 can be enlarged. The relative index difference delta in this case can be adjusted by changing width of face, the depth, etc. of the low refractive-index field 16. Therefore, according to the 10th operation gestalt, while being able to shorten bond length further, it is possible to also make loss in the optical coupling section lower.

[0054] In addition, although the low refractive-index field was prepared between each core of the optical coupling section, you may make it establish a low refractive-index field not only in between each core but in the outside of each core with the operation gestalt of the above 10th like the case of the 6th operation gestalt mentioned above besides this. Moreover, you may make it prepare a low refractive-index field about the optical directional coupler of the 9th operation gestalt.

[0055]

[Effect of the Invention] Since bond length can be shortened according to this invention when it was made for the relative index difference of the core and clad in the 3rd field to which optical coupling is performed to become larger than the relative index difference in the 1st and 5 field as explained above, it becomes possible to attain the miniaturization of an optical directional coupler, enabling connection with an optical fiber at high joint effectiveness. moreover, the refractive index of each core -- mutual -- abbreviation -- making it equal or preparing a low refractive-index field **** -- etc. -- the loss in the case of optical coupling can be low suppressed by carrying out. Therefore, a small optical directional coupler can be offered by low loss. Furthermore, if a low refractive-index field is formed by the air space, production of an optical directional coupler will become simple.

[Translation done.]

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TECHNICAL FIELD

[Field of the Invention] This invention relates to the optical directional coupler of low loss about the optical directional coupler which uses optical waveguide by small [especially connectable with an optical fiber at high joint effectiveness].

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PRIOR ART

[Description of the Prior Art] Generally, the optical directional coupler constituted using optical waveguide is an optical device for branching of light and making multiplexing, modification of a propagation path, etc., for example, is used for the wavelength filter of an optical waveguide mold, the element components of an interferometer, etc. As shown in drawing 29 , there are some which have the connection section which connects the optical coupling section which has arranged two cores of optical waveguide in parallel at narrow spacing, the close outgoing radiation section by which the core has been arranged at comparatively large spacing, and the optical coupling section and the close outgoing radiation section in the conventional optical directional coupler. In this conventional directional coupler, the configuration of a core cross section perpendicular to the travelling direction of light is the same about each of the close outgoing radiation section, the optical coupling section, and the connection section, and the relative index difference of a core and a clad is the same.
[0003] In the optical directional coupler of the above structures, if it is going to raise joint effectiveness with the single mode fiber whose mode size of the light guided is about 10 micrometers, it is necessary to bring the core size and relative index difference of optical waveguide which constitute an optical directional coupler close to the core size and relative index difference of a single mode fiber.

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EFFECT OF THE INVENTION

[Effect of the Invention] Since bond length can be shortened according to this invention when it was made for the relative index difference of the core and clad in the 3rd field to which optical coupling is performed to become larger than the relative index difference in the 1st and 5 field as explained above, it becomes possible to attain the miniaturization of an optical directional coupler, enabling connection with an optical fiber at high joint effectiveness. moreover, the refractive index of each core -- mutual -- abbreviation -- making it equal or preparing a low refractive-index field **** -- etc. -- the loss in the case of optical coupling can be low suppressed by carrying out. Therefore, a small optical directional coupler can be offered by low loss. Furthermore, if a low refractive-index field is formed by the air space, production of an optical directional coupler will become simple.

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] However, in the conventional optical directional coupler, if it is going to make an optical directional coupler into low loss when the core size and relative index difference of optical waveguide are brought close to a single mode fiber, since it will be necessary to lengthen the optical coupling section, there was a problem that an optical directional coupler will be enlarged.
[0005] Here, relation with the core size of optical waveguide, and the relative index difference and the die length of the optical coupling section which constitutes an optical directional coupler is explained briefly. First, they are the refractive index n1 of a core, and the refractive index n2 of a clad about the relative index difference delta of a core and a clad. It uses and a definition is given as follows.
delta= (n1-n2) / n2 -- (1)
If the joint effectiveness of optical waveguide and an optical fiber becomes the highest when the relative index difference delta of optical waveguide serves as a value comparable as the relative index difference of an optical fiber, as shown in drawing 30 , and relative index difference delta becomes large rather than the value, joint effectiveness will fall. Moreover, although not illustrated, if joint effectiveness becomes the highest at the time of a value comparable as the core diameter of an optical fiber and the core size of optical waveguide becomes small rather than the core diameter of an optical fiber about the core size of optical waveguide, joint effectiveness will fall.
[0006] As constraint for making optical waveguide into single mode waveguide about the relative index difference delta of an optical directional coupler, and the magnitude of a core, it may be said that magnitude of a core must be made small, so that relative index difference delta is enlarged. Drawing 31 and drawing 32 show bond length's relation to the gap width of face (spacing of two cores) of the optical coupling section of an optical directional coupler. However, core size (magnitude of one side when making a core into a square) is set constant, the relation when changing relative index difference delta is shown in drawing 31 , relative index difference delta is set constant and the relation when changing core size is shown in drawing 32 . With bond length, it considers as the shortest die length to which the optical power which carries out KOAHE migration in another side becomes 100% from one core here.
[0007] Bond length becomes short, so that gap width of face is small if core size and relative index difference delta are fixed as shown in drawing, and bond length becomes short, so that relative index difference delta is small, if core size and gap width of face are fixed. Moreover, bond length becomes short, so that core size will become small, if relative index difference delta and gap width of face are fixed. Drawing 33 shows the relation of loss of the optical coupling section to the gap width of face of the optical coupling section of an optical directional coupler according to relative index difference delta. However, core size is fixed.
[0008] If its attention is paid to the loss in the optical coupling section as shown in drawing 33 , loss becomes small, so that gap width of face is large, if relative index difference delta is fixed, and loss will become small, so that relative index difference delta is large, if gap width of face is fixed. This reason is explained as follows. As shown in drawing 34 , migration of the optical power in the optical coupling section of an optical directional coupler is produced by association with zero-order mode and the

primary mode. That is, in case the single-mode light inputted from the left end of the optical waveguide of the top of the two optical waveguides shown in the upper case of drawing 34 spreads the optical-coupling section, it will come to have electric-field distribution in zero-order mode as shown in drawing 34 (I), and electric-field distribution in the primary mode as shown in drawing 34 (II), and the electric-field distribution by the superposition in both the modes as shown in drawing 34 (III) will produce it.

[0009] Under the present circumstances, in order that the mode configuration when adding the two modes may approach the mode configuration by which a guided wave is carried out to optical waveguide of one of the two so that the minimal value (this is set to I1) of the hollow of the central part of electric-field distribution in the zero-order mode in the incidence section (A) of the optical coupling section and the outgoing radiation section (E) is small, loss becomes small at the optical coupling section. On the contrary, if the minimal value I1 of a hollow is large, since the mode configuration when adding the two modes in order not to separate on two crests where electric-field distribution in zero-order mode is beautiful will not turn into a mode configuration by which a guided wave is carried out to optical waveguide of one of the two (the component by which a guided wave is carried out in the optical waveguide of another side increases), only in the part, loss becomes large.

[0010] The minimal value I1 of the hollow of the central part in zero-order mode has the relation of becoming so small that gap width of face being large if core size and relative index difference delta are fixed, and becoming so small that core size being large if relative index difference delta and gap width of face are fixed, and becoming so small that relative index difference delta being large if gap width of face and core size are fixed. Drawing 35 sets peak intensity in zero-order mode to I0, and the relation of relative index difference delta and bond length in case I1/I0 becomes fixed (namely, when loss becomes fixed) is shown according to core size. As shown in drawing 35 , even if core size is large and it is small, it turns out that bond length becomes short, so that relative index difference delta is enlarged.

[0011] Therefore, it is small, and as one means to realize the optical directional coupler of low loss, relative index difference delta of a core and a clad is enlarged, and it is thought effective to adjust core size according to it. As an optical device of the directivity joint mold which gave the description to refractive-index distribution of optical waveguide, the guided wave mold optical switch indicated by JP,4-19713,A etc., for example is well-known. This guided wave mold optical switch is enlarging the refractive-index difference of two approaching optical waveguides, namely, giving a difference to the refractive index of each core of the optical waveguide located in the optical coupling section, and tends to enlarge the difference of the propagation constant (velocity of propagation) in zero-order mode and the primary mode.

[0012] However, in the above-mentioned guided wave mold optical switch, since field strength distribution in the zero-order mode in the optical coupling section and the primary mode becomes unsymmetrical in two optical waveguides as shown in drawing 36 , the field strength distribution after interference does not become a single crest. For this reason, when the above well-known techniques are applied to the optical directional coupler of refractive-index immobilization, problems, such as an increment in loss and a fall of an extinction ratio, will arise.

[0013] This invention was made paying attention to the above-mentioned point, and it is small and it aims at the thing which can connect with an optical fiber at high joint effectiveness and for which the optical directional coupler of low loss is offered.

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MEANS

[Means for Solving the Problem] for this reason, in the 1st field and the 5th field in which the optical directional coupler of this invention has two optical waveguides continued and prepared in the 1-5th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3rd field Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 4th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively, the relative index difference of the core and clad in the 3rd field makes said each optical waveguide at least larger than the relative index difference of the core and clad in the 1st field and the 5th field.
[0015] According to this configuration, the light by which incidence was carried out to one optical waveguide of the 1st field spreads to the 3rd field through the 2nd field, for example. In the 3rd field, since two optical waveguides are approaching, the light which has spread one optical waveguide is outputted from the optical waveguide of another side, and spreads to the 5th field through the 4th field. Under the present circumstances, the die length of the 3rd field, i.e., bond length, becomes short by relative index difference of the 3rd field where optical coupling is performed being made larger than the 1st field and the 5th field. Moreover, since the relative index difference of the 1st field and the 5th field is small, it becomes connectable with an optical fiber at high joint effectiveness.
[0016] Moreover, as for said each optical waveguide, it is desirable to make it become [on which the refractive index of the core in the 3rd field spreads abbreviation etc. mutually at least]. the refractive index of each core of two optical waveguides -- abbreviation -- by making it equal, since the field strength in the zero-order mode in each optical waveguide of the 3rd field and the primary mode serves as symmetrical distribution, the field strength distribution after interference serves as a single crest mostly, and the loss in the case of optical coupling becomes low.
[0017] Furthermore, it has the core of the double structure which consists of the inside core and the outside core which has a low refractive index relatively which has a high refractive index relatively as a concrete configuration of each of said optical waveguide, respectively, and the core width of face of each of said optical waveguide located in the 3rd field at least may be made to be made into the width of face of said inside core, respectively. In addition, about the above-mentioned optical directional coupler, it is desirable to be prepared between the cores of each of said optical waveguide located in the 3rd field at least, to have a low refractive-index field with a low refractive index, and to consist of refractive indexes of a clad. This low refractive-index field may be formed by the air space. Thus, while the relative index difference of the 3rd field becomes larger and bond length becomes short by preparing a low refractive-index field, the refractive index between the cores of the optical coupling section becomes low, and loss becomes small.
[0018] Moreover, as for said each optical waveguide, it is desirable to make it the core width of face of the part in which said low refractive-index field is established become narrower than the core width of face of other parts. Thereby, optical coupling section core size becomes small, and bond length becomes

still shorter. Furthermore, said low refractive-index field may be made to establish between the cores of each of said optical waveguide located in the 3rd field at least, and in the outside of each core. By doing in this way, the relative index difference of the core in the 3rd field and a clad becomes still larger.
[0019] moreover, in the 1st field and the 9th field in which other optical directional couplers concerning this invention have two optical waveguides continued and prepared in the 1-9th fields which continue along the propagation direction of light, and close outgoing radiation of the light is carried out Spacing between each optical waveguide is relatively made large so that light may spread independently the inside of said each optical waveguide. In the 3-7th fields Spacing between each optical waveguide is relatively narrowed so that the light which spreads the inside of said each optical waveguide may interact. In the 2nd field and the 8th field In the optical directional coupler of a configuration of that each optical waveguide of an adjoining field is connected, respectively Spacing between said each optical waveguide located in the 5th field is made narrower than spacing between said each optical waveguide located in the 3rd field and the 7th field, and each optical waveguide of the 5th field considers as the configuration connected with each optical waveguide of the 3rd field and the 7th field through the 4th field and the 6th field.
[0020] Since spacing between each core of the 3rd and 7 field is larger than core spacing of the 5th field while bond length becomes short according to this configuration, since the 5th field located in the central part of the 3-7th fields used as the optical coupling section turns into a strong optical coupling field, the loss in the optical coupling section comes to be suppressed low. Furthermore, you may make it said each optical waveguide become narrower than the width of face of the core to which the width of face of the core located in the 5th field at least is located in other fields. In addition, about the above-mentioned optical directional coupler, it is desirable to be prepared between the cores of each of said optical waveguide located in the 3-7th fields at least, to have a low refractive-index field with a low refractive index, and to consist of refractive indexes of a clad.
[0021]
[Embodiment of the Invention] Hereafter, the operation gestalt of this invention is explained based on a drawing. Drawing 1 is the plan showing the configuration of the optical directional coupler concerning the 1st operation gestalt. Moreover, drawing 2 is (a) shown with the alternate long and short dash line of drawing 1 . - (e) It is the sectional view which can be set. In drawing, this optical directional coupler consists of optical waveguide layers which used polyimide etc. and were formed for example, on the silicon substrate 10 and this silicon substrate 10. An optical waveguide layer consists of two cores 12 surrounded by the clad 11, each core 12 is formed in parallel with a longitudinal direction by drawing 1 , and mutual spacing is narrow in the central part. Here, the part (close outgoing radiation section) located in a right-and-left edge by drawing 1 is made into the 1st field and the 5th field, make into the 3rd field the part (optical coupling section) to which spacing of each core 12 located in the center became narrow, and let the parts (connection section) located between the 1st field and the 5th field, and the 3rd field be the 2nd field and the 4th field.
[0022] Each core 12 has the double core fabric which consists of core (inner core) 12B located in core (outer core) 12A and the inside which are located outside. Outer core 12A is formed near the edge of the 1st field where connection with a single mode fiber etc. is made, and the 5th field (refer to drawing 2 (a) and (e)), and becomes connectable with a single mode fiber at high joint effectiveness by having the large cross-sectional area in a connection end face. The cross section is made narrower than outer core 12A, and it is formed in the 2nd field - the 4th field, applying inner core 12B. moreover, the refractive index of the part which two cores 12 counter -- mutual -- abbreviation -- it is made to become equal, and it is set up so that two cores 12 may have symmetrical structure.
[0023] Conversion to inner core 12B from outer core 12A is performed by joining each core formed in the shape of a taper in the 1st field and the 5th field. The core cross section of this conversion part serves as double structure, as shown in drawing 2 (b) and (d). In addition, although it was made to perform conversion to inner core 12B from outer core 12A in the 1st field and the 5th field, it may be made to carry out not only this but in the 2nd field and the 4th field. However, if it changes in the 1st field and the 5th field, since the core of the 2nd field and the 4th field can be made thin and radius of curvature

can be made small, an optical directional coupler will become smaller.

[0024] The refractive index (n1o) of outer core 12A is higher than the refractive index (n2) of a clad 11, and the refractive index (n1i) of inner core 12B is made higher than the refractive index (n1o) of outer core 12A. That is, the refractive index of optical waveguide is set up so that it may have the following size relation.

n1 i>n1 o>n2 -- here shows the example of each set point in the 1st operation gestalt. Core size is set to width-of-face W1=4micrometerx height H1=7micrometer about inner core 12B, and it is refractive-index n1i 1.532 It carries out. Core size is set to width-of-face W2=7micrometerx height H2=7micrometer about outer core 12A, and it is refractive-index n1o 1.528 It carries out. About a clad 11, it is a refractive index n2. 1.520 It carries out and thickness of 10 micrometers and an exaggerated clad is set to 15 micrometers for the thickness of an undershirt clad. Moreover, by such setup, it is the gap width of face G1 between the cores in the 3rd field 5.5 Bond length will be set to 5.4 mm if mum.

[0025] Moreover, the formation approach of the double core fabric mentioned above is explained briefly. Drawing 3 is the formation approach of a double core fabric of having used for example, fluorination polyimide. In addition, although fluorination polyimide was used here, this invention is not restricted to this. However, if an organic material like fluorination polyimide is used, a double core fabric can be produced comparatively easily.

[0026] In drawing 3 , sequential formation of a cladding layer, an outer core layer, and the inner core layer is first carried out by the spin coat on a silicon substrate 10. Next, after forming the mask equivalent to inner core width of face on an inner core layer, a part of inner core layer and outer core layer are etched by reactive ion etching (RIE), and an outer core layer is further applied so that an inner core may be surrounded.

[0027] Next, in forming the double core part located in the 1st field or the 5th field, after forming the mask equivalent to outer core width of face on an outer core layer, RIE removes an unnecessary outer core layer, an outer core is formed, a cladding layer is applied so that an outer core may be surrounded further, and the double core fabric of the 1st field or the 5th field is formed. In forming the core part located in the 2nd - the 4th field, after, forming the mask equivalent to inner core width of face on an outer core layer on the other hand, RIE removes an unnecessary outer core layer. However, an outer core will remain in the upper and lower sides of an inner core in this case. And a cladding layer is applied so that a core may be surrounded, and the double core fabric of the 2nd - the 4th field is formed.

[0028] In the optical directional coupler which has the double core fabric formed as mentioned above, in connection with a single mode fiber, since it connects with outer core 12A with big core size, joint effectiveness higher than the conventional optical directional coupler is realized. On the other hand, in the optical coupling section of the 3rd field, since inner core 12B which made the refractive index high is formed and the relative index difference delta of a clad 11 and a core 12 is large, bond length (the die length of the 3rd field) can be shortened. In the conventional optical directional coupler (for example, core width of face is 7 micrometers, and relative index difference delta is 0.5 etc.) which does not specifically have the inner core which made the refractive index high, although bond length is set to about 10mm, bond length becomes 5.4 mm extent by using the structure of this operation gestalt. Therefore, a small optical directional coupler is comparatively realizable by low loss. Moreover, in the optical coupling section, by making width of face of a core 12 into inner core width of face, and adjusting a setup of this width of face suitably, even if relative index difference delta becomes large, it is possible to maintain a single mode.

[0029] Next, the 2nd operation gestalt of this invention is explained. Drawing 4 is the plan showing the configuration of the optical directional coupler concerning the 2nd operation gestalt. Moreover, drawing 5 is (a) shown with the alternate long and short dash line of drawing 4 . - (c) It is the sectional view which can be set. In drawing, this optical directional coupler is taken as the configuration which formed the low refractive-index field 13 between each core located in the 3rd field (optical coupling section) at least, in order to form two cores 12 surrounded by the clad 11 on the silicon substrate 10 and to enlarge relative index difference delta of the clad 11 and core 12.

[0030] Unlike the case of the 1st operation gestalt, each core 12 shall have single core size and a single refractive index (n1). When an example is shown, core size is set to width-of-face W3=7micrometerx height H3=7micrometer, and it is a refractive index n1. 1.530 It carries out. Moreover, it is the gap width of face G2 between each core 5.5 It is referred to as mum. Furthermore, about a clad 11, it is the refractive index n2 1.522 It carries out.

[0031] The low refractive-index field 13 has the width of face below the gap width of face between each core 12 in the 3rd field, and is the refractive index n2 of a clad 11. Low refractive index n3 It is the field which it has. the optical directional coupler for which this low refractive-index field 13 used polyimide -- etching -- a slot -- forming -- there -- a clad 11 -- low -- if the refractive index matter is applied, it can form. the cross-section configuration of the low refractive-index field 13 -- for example, drawing 6 (A) - (D) etc. -- considering as various configurations as shown is possible. Here, as a concrete example of a setting of the low refractive-index field 13, it is referred to as width-of-face W4=4micrometerx depth D4=4micrometerx die-length L4=6000micrometer, and is a refractive index n3. 1.520 It carries out.

[0032] According to the optical directional coupler of the above structures, since relative index difference delta in the optical coupling section can be enlarged, bond length can be shortened. Moreover, relative index difference delta is the width of face, the depth, and the refractive index n3 of the low refractive-index field 13. It can adjust by changing. Furthermore, from the refractive index between the cores in the optical coupling section falling, since the minimal value Il of the hollow of the central part of electric-field distribution in the zero-order mode shown in above-mentioned drawing 34 (I) becomes low, loss in the optical coupling section can be made low. Therefore, according to the 2nd operation gestalt, it can connect with a single mode fiber at high joint effectiveness like the case of the 1st operation gestalt, and a small optical directional coupler can be realized by low loss.

[0033] Next, the 3rd operation gestalt of this invention is explained. Drawing 7 is the plan showing the configuration of the optical directional coupler concerning the 3rd operation gestalt. Moreover, drawing 8 is (a) shown with the alternate long and short dash line of drawing 7 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, this optical directional coupler replaces with the low refractive-index field 13, and forms an air gap (air space) 14. Configurations other than the above are the same as the configuration of the 2nd operation gestalt.

[0034] If an air gap 14 is the optical waveguide which used a quartz system and fluorination polyimide, it is simply producible by etching. moreover, the case of the cross-section configuration of the low refractive-index field 13 which mentioned above the cross-section configuration of an air gap 14 -- the same -- for example, drawing 9 (A) - (D) etc. -- considering as various configurations as shown is possible. Here, a width-of-face W5=4micrometerx depth D5=4micrometerx die-length L5=6000micrometer thing is used as an example of an air gap 14.

[0035] According to the optical directional coupler of the above structures, like the case of the 2nd operation gestalt, since relative index difference delta in the optical coupling section can be enlarged, bond length can be shortened. Moreover, relative index difference delta can be adjusted by changing the width of face and the depth of an air gap 14. Furthermore, since the refractive index between the cores in the optical coupling section falls, loss in the optical coupling section can also be made low. In addition, an air gap 14 also has the advantage that it can form easily compared with the low refractive-index field 13.

[0036] Next, the 4th operation gestalt of this invention is explained. Drawing 10 is the plan showing the configuration of the optical directional coupler concerning the 4th operation gestalt. Moreover, drawing 11 is (a) shown with the alternate long and short dash line of drawing 10 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, core size covers an overall length, and this optical directional coupler is replaced with two uniform cores 12, and prepares two core 12' which made smaller than the part located in other fields core size of the part located in the 3rd field. Configurations other than the above are the same as the configuration of the 2nd operation gestalt.

[0037] Each core 12' about the part located in the 1st field and the 5th field The size of the part which has the same size as the core 12 used with the 2nd operation gestalt, and is located in the 3rd part For example, it was referred to as width-of-face W6=4micrometerx height H6=4micrometer, and the part located in the 2nd field and the 4th field was formed in the shape of a taper, and has connected the 3rd field, the 1st field, and the 5th field. Moreover, refractive index n1 of the core in each field It is set up so that it may become equal, for example, it is refractive-index n1 =1.530. It is carried out. The relative index difference delta at the time of using this core 12' can be adjusted by changing width of face, the depth, etc. of the low refractive-index field 13.

[0038] According to this configuration, optical waveguide will become a multimode if core size becomes [relative index difference delta] large in a fixed case. In single mode ******, relative index difference delta can be enlarged, so that core size is made small. If relative index difference delta is enlarged and core size is made small as shown in above-mentioned drawing 35 , bond length can be shortened with a single mode maintained. Therefore, according to the above-mentioned configuration, a smaller optical directional coupler will be realized more by low loss. Moreover, in the part located in the 1st field and the 5th field, joint effectiveness with a single mode fiber is highly maintained for core size by that in the size case.

[0039] In addition, although it was made to make thin the core of the part located in the 3rd field with the 4th operation gestalt mentioned above, as shown in drawing 12 , not only the optical coupling section but the core of the part located in the 2nd field and the 4th field may be made thin. If it does in this way, since the curvature for a bend section of the 2nd field and the 4th field can be made small, an optical directional coupler can be made still smaller. Moreover, the low refractive-index field 13 of the 4th above-mentioned operation gestalt may be replaced with an air gap 14 like the case of the 3rd operation gestalt.

[0040] Next, the 5th operation gestalt of this invention is explained. Drawing 13 is the plan showing the configuration of the optical directional coupler concerning the 5th operation gestalt. Moreover, drawing 14 is (a) shown with the alternate long and short dash line of drawing 13 . - (e) It is the sectional view which can be set. In drawing, like the case of the 3rd operation gestalt, this optical directional coupler forms an air gap 14 between each core of the 3rd field at least, and enlarges relative index difference delta of a clad 11 and core 12B about the optical directional coupler of the double core fabric of the 1st operation gestalt mentioned above. In addition, the air gap 14 used here can also be made into the same low refractive-index field 13 as the case of the 2nd operation gestalt mentioned above.

[0041] In the optical directional coupler of such a configuration, since relative index difference delta in the optical coupling section can be enlarged by having considered as the double core fabric, without lowering joint effectiveness with a single mode fiber, bond length can be shortened further. Moreover, since the minimal value Il of the hollow of the central part in the zero-order mode mentioned above can be made low by having formed the air gap 14, loss in the optical coupling section can be made low.

[0042] Next, the 6th operation gestalt of this invention is explained. Drawing 15 is the plan showing the configuration of the optical directional coupler concerning the 6th operation gestalt. Moreover, drawing 16 is (a) shown with the alternate long and short dash line of drawing 15 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 2nd operation gestalt, this optical directional coupler prepares low refractive-index field 13' not only in between each core 12 but in the outside of each core 12 in the 3rd field at least, in order to enlarge more relative index difference delta of a clad 11 and a core 12. Other configurations are the same as the configuration of the 2nd operation gestalt.

[0043] Low refractive-index field 13' is continued and formed near the boundary of the 4th and 5 field from near the boundary of the 1st and 2 field here, and the cross-section configuration is drawing 16 (b). It has the part projected between two cores 12 and on the outside of each core 12 so that it may be shown. in addition, the cross-section configuration of low refractive-index field 13' -- drawing 17 (A) - (D) etc. -- considering as various configurations as shown is possible. It is possible to adjust suitably the relative index difference delta of a clad 11 and a core 12 by changing width of face, the depth, etc. of this low refractive-index field 13'.

[0044] In the optical directional coupler of such a configuration, since the relative index difference delta in the optical coupling section becomes still larger compared with the case of the 2nd operation gestalt, it is possible to shorten bond length more. Moreover, like the case of the 2nd operation gestalt, since the refractive index between each core 12 falls, the minimal value Il of the hollow of the center in zero-order mode becomes small, and serves as low loss. Therefore, according to the 6th operation gestalt, it is more small and the optical directional coupler of low loss can be realized.

[0045] Next, the 7th operation gestalt of this invention is explained. Drawing 18 is the plan showing the configuration of the optical directional coupler concerning the 7th operation gestalt. Moreover, drawing 19 is (a) shown with the alternate long and short dash line of drawing 18 . - (c) It is the sectional view which can be set. In drawing, about the optical directional coupler of the 6th operation gestalt, this optical directional coupler replaces with low refractive-index field 13', and prepares air gap (air space) 14'. This configuration is the same as that also of what replaced with air gap 14' the air gap 14 used with the 3rd operation gestalt. Configurations other than the above are the same as the configuration of the 6th operation gestalt.

[0046] If this air gap 14' is the optical waveguide which used a quartz system and fluorination polyimide, it is simply producible by etching. moreover, the case of the cross-section configuration of low refractive-index field 13' which mentioned above the cross-section configuration of air gap 14' -- the same -- for example, drawing 20 (A) - (D) etc. -- considering as various configurations as shown is possible. It is possible to adjust suitably the relative index difference delta of a clad 11 and a core 12 by changing width of face, the depth, etc. of this air gap 14'.

[0047] According to the optical directional coupler of the above structures, like the case of the 6th operation gestalt, since the relative index difference delta in the optical coupling section becomes still larger, bond length can be shortened more and loss in the optical coupling section can also be made low. Furthermore, air gap 14' also has the advantage that it can form easily compared with low refractive-index field 13'. In addition, although the above-mentioned 6th and the operation gestalt of 7 explained the case where low refractive-index field 13' and air gap 14' were applied about the operation gestalt of the 2nd and 3, not only this but, of course, this invention can apply low refractive-index field 13' and air gap 14' about the operation gestalt of the 4th and 5. In drawing 21 and drawing 22 , the plan and each sectional view at the time of applying low refractive-index field 13' are shown about the 4th operation gestalt, and the plan and each sectional view at the time of applying low refractive-index field 13' about the 5th operation gestalt are shown in drawing 23 and drawing 24 at them.

[0048] Next, the 8th operation gestalt of this invention is explained. Drawing 25 is the plan showing the configuration of the optical directional coupler concerning the 8th operation gestalt. In drawing 25 , this optical directional coupler establishes the strong optical coupling field which made still narrower gap width of face between two cores 15 in the central part of the optical coupling section about the conventional optical directional coupler. In drawing, the close outgoing radiation section of the conventional optical directional coupler is made into the 1st and 9 field, the connection section is made into the 2nd and 8 field, and the optical coupling section is made into the 3-7th fields. The 3-7th fields used as the optical coupling section consist of the 4th and 6 fields which connect the 3rd and 7 field which has the same gap width-of-face G3 as usual, the 5th field as a strong optical coupling field which has the still narrower gap width of face G4, and the 3rd and 7 field and the 5th field. As a concrete example of a setting, width of face of each core 15 is set to 7 micrometers, height is set to 7 micrometers, and gap width of face G4 in the 5th field is set to 4 micrometers. In addition, the configuration except having established the strong optical coupling field in the optical coupling section is the same as the configuration of the conventional optical directional coupler.

[0049] In the optical directional coupler of such a configuration, since the gap width of face in the optical coupling section becomes narrower by having prepared the strong optical coupling field, bond length can be shortened. However, if gap width of face in all the 3-7th fields is narrowed, as mentioned above, the minimal value Il of the hollow of the center of electric-field distribution in zero-order mode will become large, and the loss in the optical coupling section will increase. In order to prevent this, by making large gap width of face of the optical ON outgoing radiation part (the 3rd and 7 field) of the optical coupling section as usual, said minimal value Il can be maintained small and the increment in loss can be prevented. Therefore, according to the 8th operation gestalt, the optical directional coupler aiming at a miniaturization can be realized about the conventional optical directional coupler, without making loss increase.

[0050] Next, the 9th operation gestalt of this invention is explained. Drawing 26 is the plan showing the configuration of the optical directional coupler concerning the 9th operation gestalt. In drawing 26 , this optical directional coupler is replaced with each core 15 which has uniform core size about the operation gestalt of the above 8th, and is taken as the configuration which prepared core 15' which made small core size of the part located in a strong optical coupling field (the 5th field) at least. Specifically, width of face of each core 15' in a strong optical coupling field is set to 4 micrometers. Configurations other than the above are the same as the configuration of the 8th operation gestalt.

[0051] In such an optical directional coupler, if gap width of face and relative index difference delta are in a fixed condition as shown in above-mentioned drawing 32 , the one where core size is smaller can shorten bond length. Therefore, according to the 9th operation gestalt, the same effectiveness as the 8th operation gestalt is acquired, and bond length can be shortened further. Next, the 10th operation gestalt of this invention is explained.

[0052] Drawing 27 is the plan showing the configuration of the optical directional coupler concerning the 10th operation gestalt. Moreover, drawing 28 is (a) shown with the alternate long and short dash line of drawing 27 . - (e) It is the sectional view which can be set. In drawing, this optical directional coupler is taken as the configuration which formed the low refractive-index field 16 between each core located in the 3-7th fields (optical coupling section) at least like the case of the 2nd operation gestalt about the optical directional coupler of the 8th operation gestalt. It is prepared applying the low refractive-index field 16 in the middle of the 8th field from the middle of the 2nd field here, and the width of face is made below into the gap width of face between the cores in a strong optical coupling field. in addition, the cross-section configuration of the low refractive-index field 16 -- drawing 28 (c) Not only the shown configuration but above-mentioned drawing 6 (A) - (D) etc. -- considering as various configurations as shown is possible. Moreover, it replaces with the low refractive-index field 16 used here, and you may make it prepare the same air gap as the case of the 3rd operation gestalt.

[0053] In such an optical directional coupler, since the refractive index between the cores in the optical coupling section falls by having formed the low refractive-index field 16, relative index difference delta of a clad 11 and a core 15 can be enlarged. The relative index difference delta in this case can be adjusted by changing width of face, the depth, etc. of the low refractive-index field 16. Therefore, according to the 10th operation gestalt, while being able to shorten bond length further, it is possible to also make loss in the optical coupling section lower.

[0054] In addition, although the low refractive-index field was prepared between each core of the optical coupling section, you may make it establish a low refractive-index field not only in between each core but in the outside of each core with the operation gestalt of the above 10th like the case of the 6th operation gestalt mentioned above besides this. Moreover, you may make it prepare a low refractive-index field about the optical directional coupler of the 9th operation gestalt.

[Translation done.]

* NOTICES *

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1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the plan showing the configuration of the 1st operation gestalt of this invention.
[Drawing 2] the same as the above -- (a) of drawing 1 of the 1st operation gestalt - (e) It is each sectional view which can be set.
[Drawing 3] the same as the above -- it is drawing explaining an example of the formation approach of the double core fabric in the 1st operation gestalt.
[Drawing 4] It is the plan showing the configuration of the 2nd operation gestalt of this invention.
[Drawing 5] the same as the above -- (a) of drawing 4 of the 2nd operation gestalt - (c) It is each sectional view which can be set.
[Drawing 6] the same as the above -- it is the instantiation Fig. of the cross-section configuration of the low refractive-index field of the 2nd operation gestalt.
[Drawing 7] It is the plan showing the configuration of the 3rd operation gestalt of this invention.
[Drawing 8] the same as the above -- (a) of drawing 7 of the 3rd operation gestalt - (c) It is each sectional view which can be set.
[Drawing 9] the same as the above -- it is the instantiation Fig. of the cross-section configuration of the air gap of the 3rd operation gestalt.
[Drawing 10] It is the plan showing the configuration of the 4th operation gestalt of this invention.
[Drawing 11] the same as the above -- (a) of drawing 10 of the 4th operation gestalt - (c) It is each sectional view which can be set.
[Drawing 12] the same as the above -- it is the plan showing other examples of a configuration about the 4th operation gestalt.
[Drawing 13] It is the plan showing the configuration of the 5th operation gestalt of this invention.
[Drawing 14] the same as the above -- (a) of drawing 13 of the 5th operation gestalt - (e) It is each sectional view which can be set.
[Drawing 15] It is the plan showing the configuration of the 6th operation gestalt of this invention.
[Drawing 16] the same as the above -- (a) of drawing 15 of the 6th operation gestalt - (c) It is each sectional view which can be set.
[Drawing 17] the same as the above -- it is the instantiation Fig. of the cross-section configuration of the low refractive-index field of the 6th operation gestalt.
[Drawing 18] It is the plan showing the configuration of the 7th operation gestalt of this invention.
[Drawing 19] the same as the above -- (a) of drawing 18 of the 7th operation gestalt - (c) It is each sectional view which can be set.
[Drawing 20] the same as the above -- it is the instantiation Fig. of the cross-section configuration of the air gap of the 7th operation gestalt.
[Drawing 21] It is the plan showing the configuration at the time of applying to the configuration of the 4th operation gestalt about the operation gestalt of the 6th and 7.
[Drawing 22] (a) of drawing 21 - (c) It is each sectional view which can be set.
[Drawing 23] It is the plan showing the configuration at the time of applying to the configuration of the

5th operation gestalt about the operation gestalt of the 6th and 7.
[Drawing 24] (a) of drawing 23 - (c) It is each sectional view which can be set.
[Drawing 25] It is the plan showing the configuration of the 8th operation gestalt of this invention.
[Drawing 26] It is the plan showing the configuration of the 9th operation gestalt of this invention.
[Drawing 27] It is the plan showing the configuration of the 10th operation gestalt of this invention.
[Drawing 28] the same as the above -- (a) of drawing 27 of the 10th operation gestalt - (e) It is each sectional view which can be set.
[Drawing 29] It is the plan showing the configuration of the conventional optical directional coupler.
[Drawing 30] It is drawing showing the relation between joint effectiveness with an optical fiber, and relative index difference.
[Drawing 31] It is drawing having shown bond length's relation to the gap width of face of the optical coupling section at the time of seting core size constant.
[Drawing 32] It is drawing having shown bond length's relation to the gap width of face of the optical coupling section at the time of seting relative index difference constant.
[Drawing 33] It is drawing having shown the relation of the loss over the gap width of face of the optical coupling section.
[Drawing 34] It is drawing explaining the situation of migration of the optical power in the optical coupling section.
[Drawing 35] It is drawing having shown bond length's relation to the relative index difference at the time of seting loss constant.
[Drawing 36] It is drawing showing the field strength distribution in the optical coupling section of the conventional guided wave mold optical switch.
[Description of Notations]
10 -- Silicon substrate
11 -- Clad
12, 12', 15, 15' -- Core
12A -- Outer core
12B -- Inner core
13, 13', 16 -- Low refractive-index field
14 14' -- Air gap

[Translation done.]

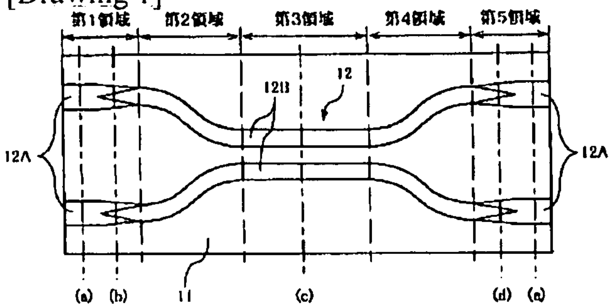
* NOTICES *

JPO and NCIPI are not responsible for any
damages caused by the use of this translation.

1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DRAWINGS

[Drawing 1]



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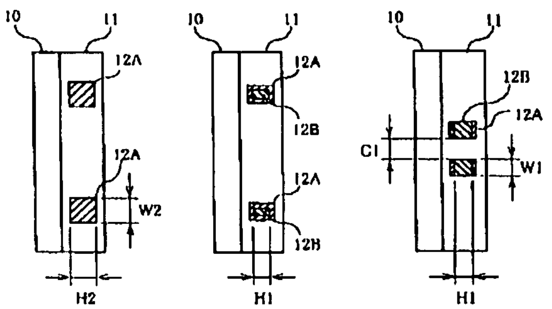

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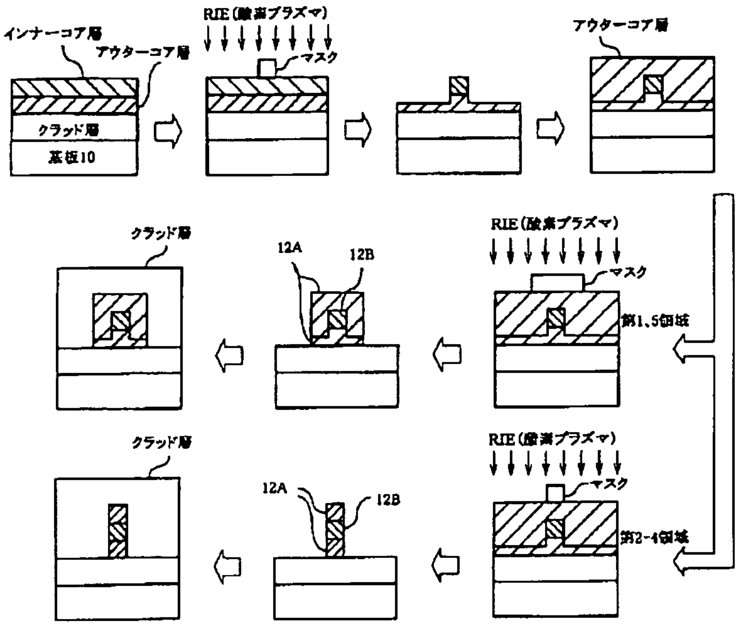

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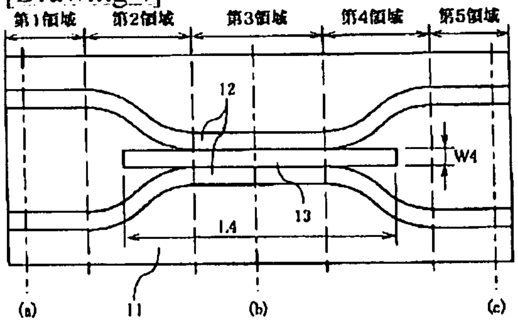

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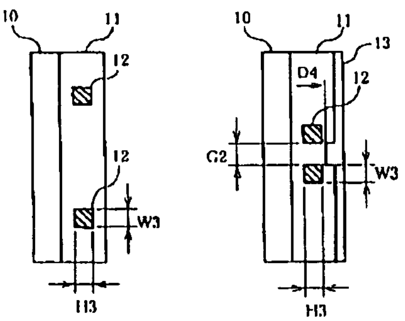

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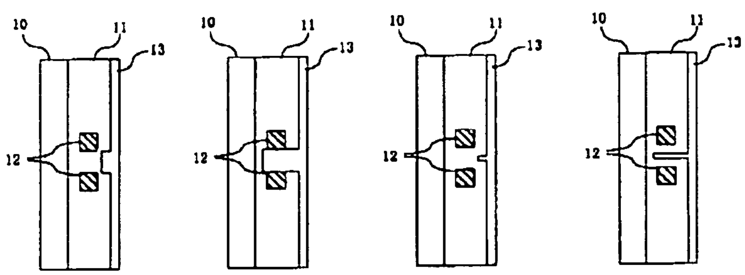

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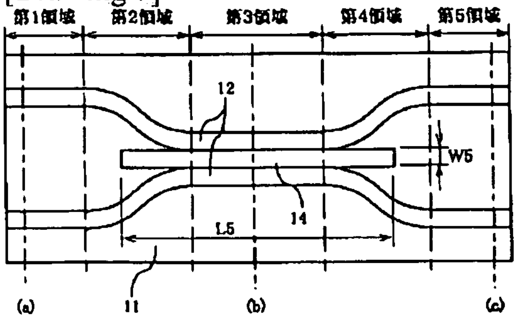

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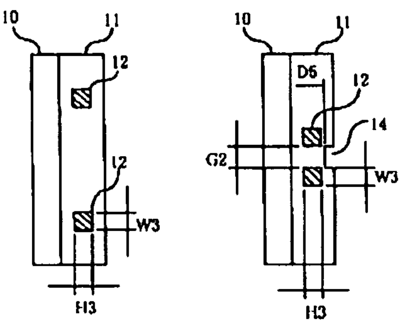

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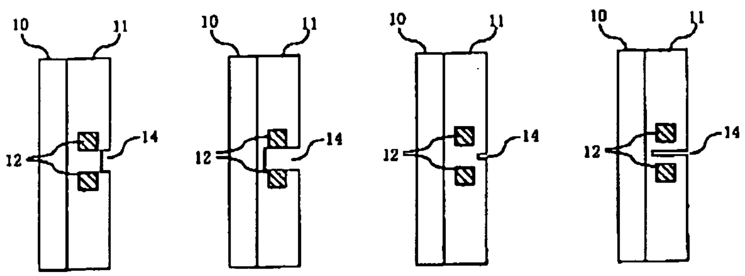

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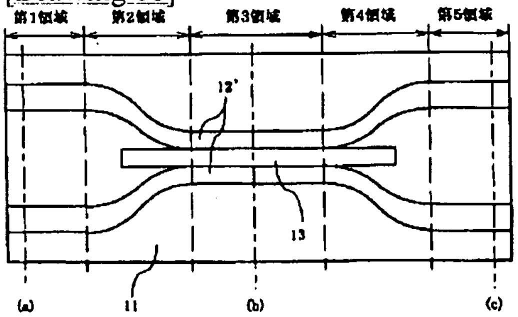

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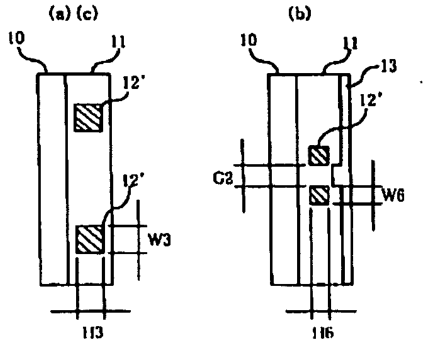

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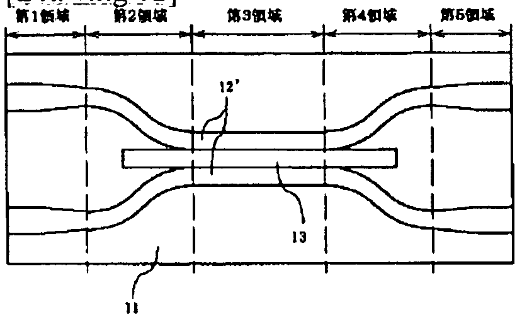

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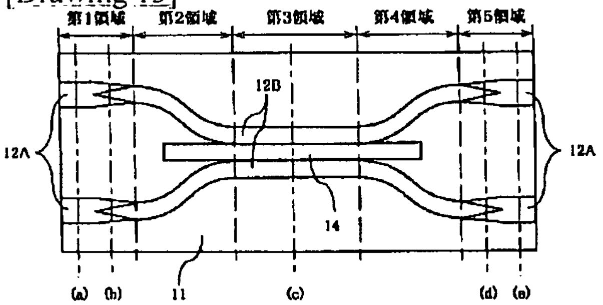

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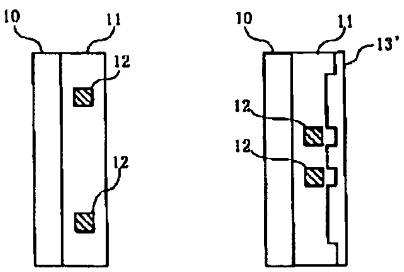

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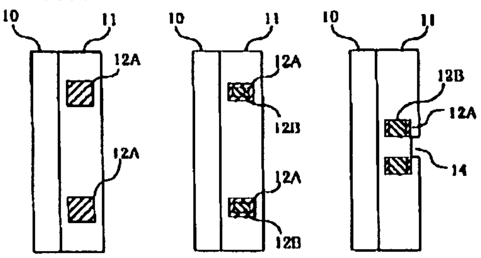

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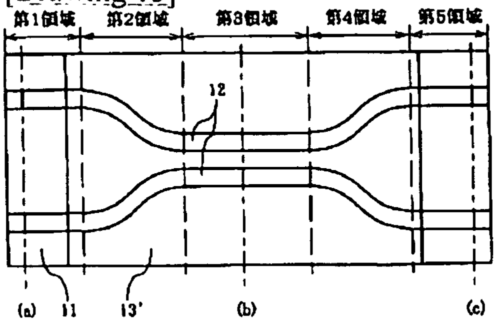

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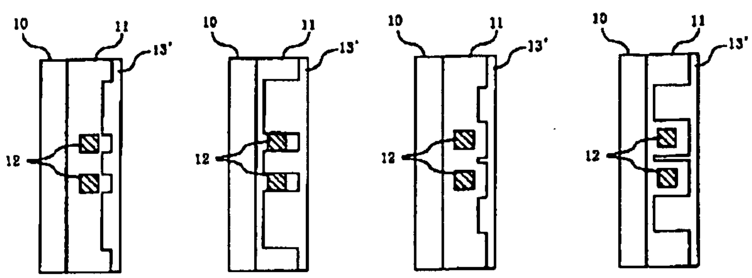

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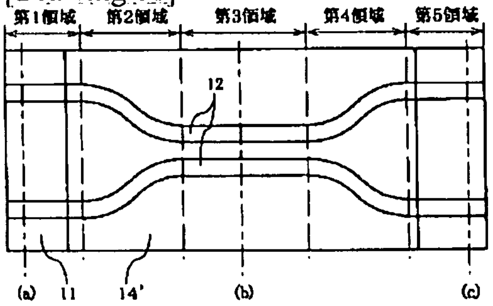

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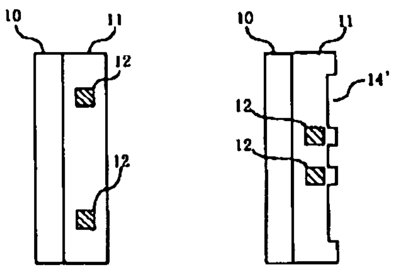

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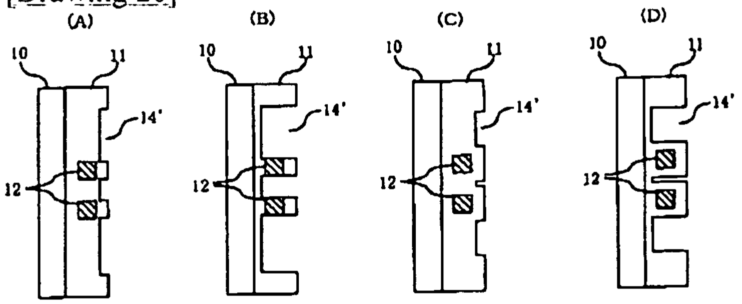

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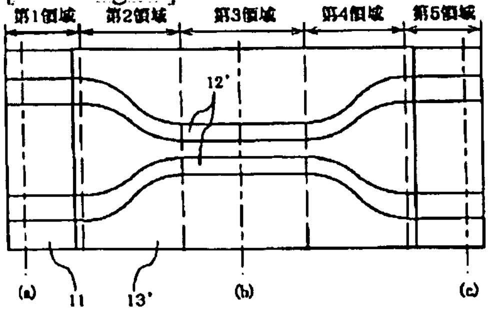

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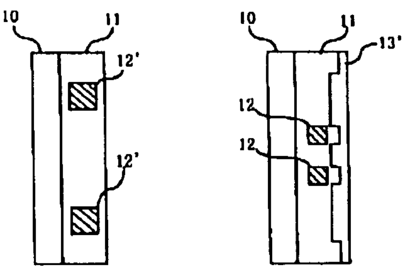

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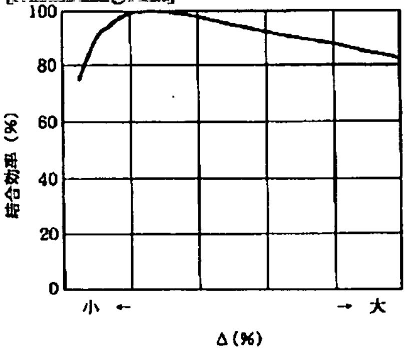

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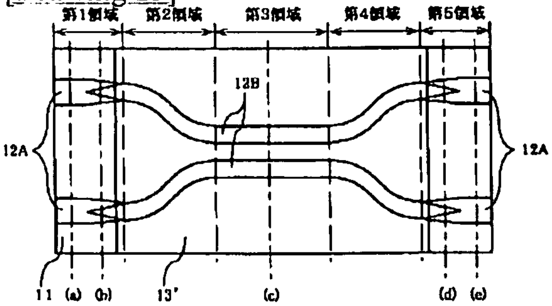

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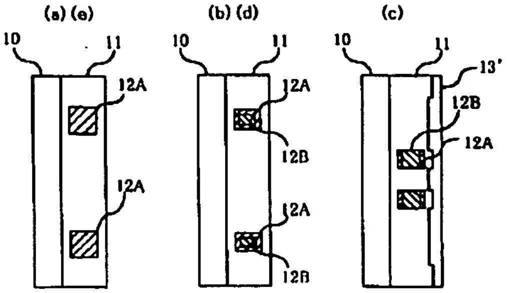

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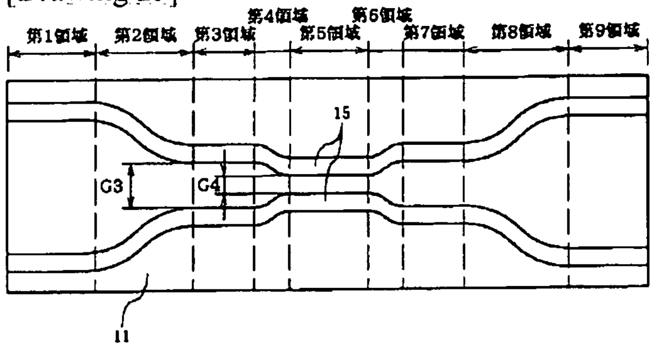

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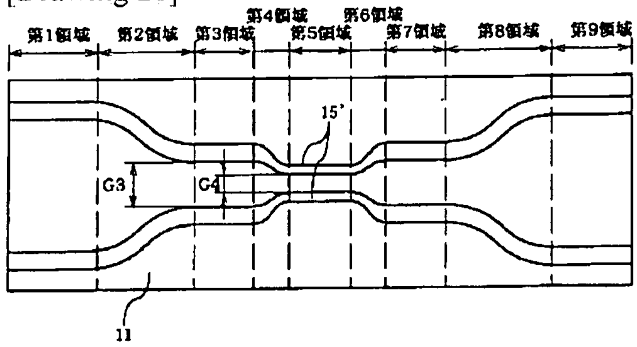

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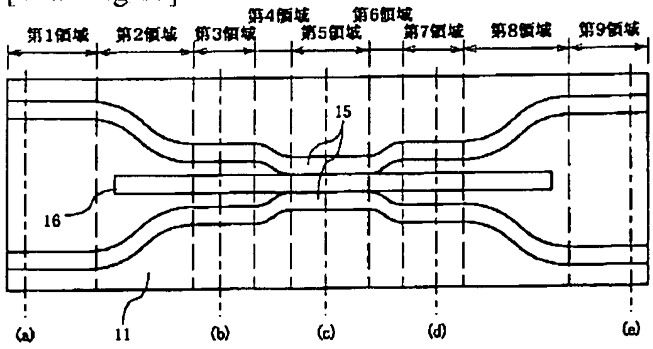

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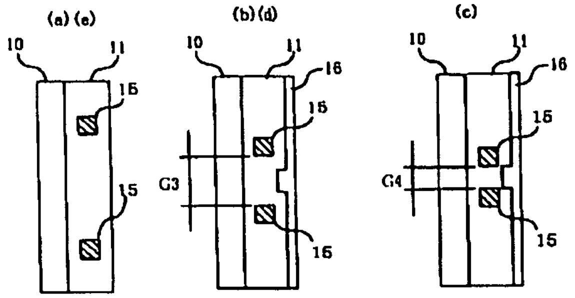

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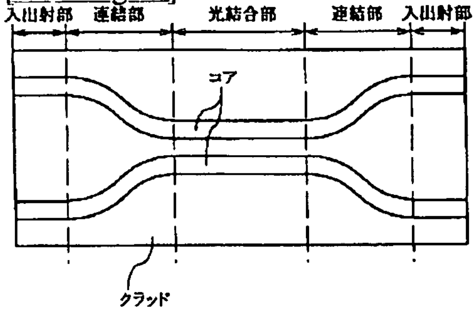

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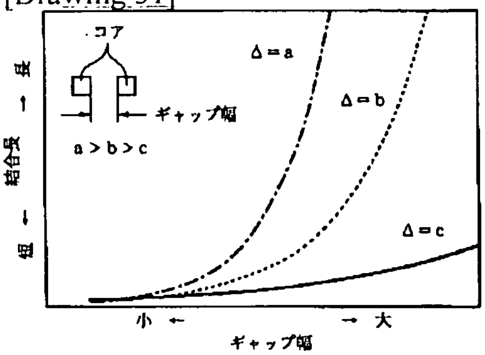

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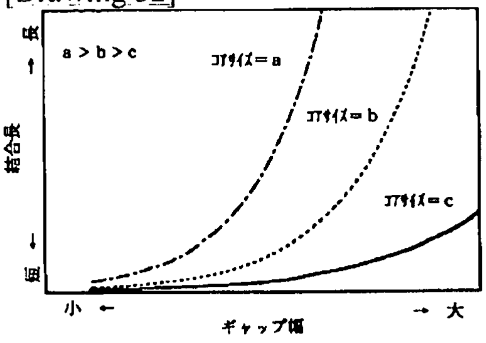

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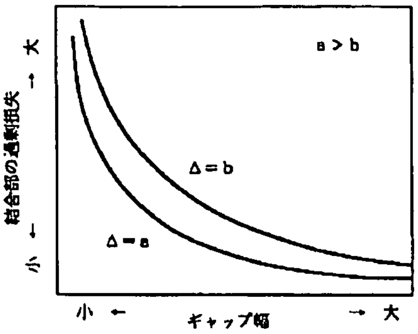

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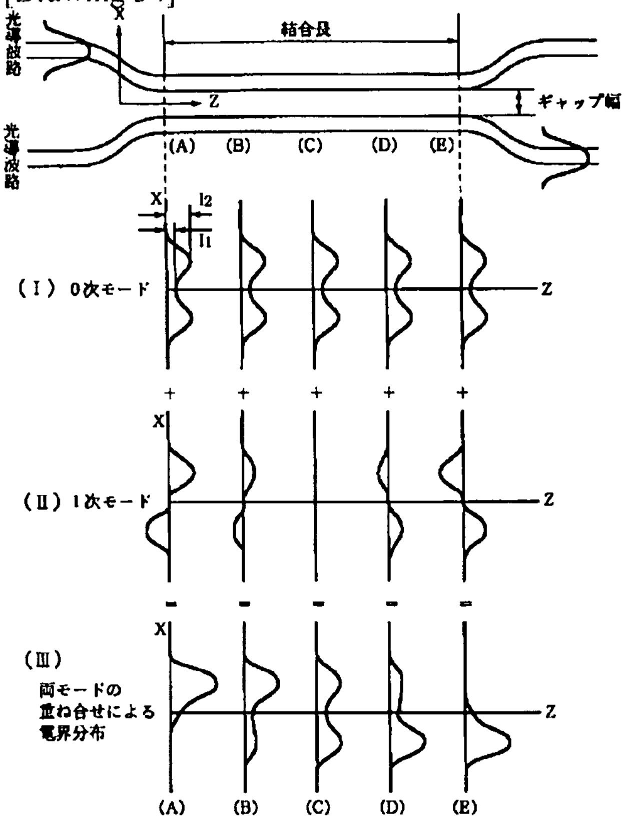

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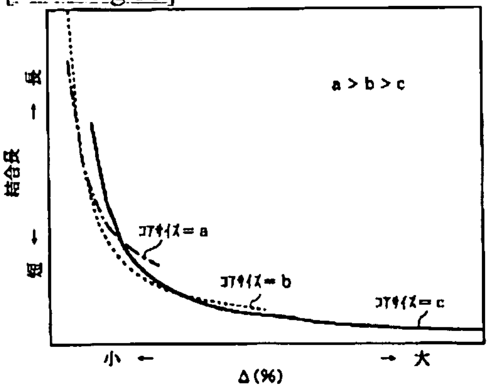

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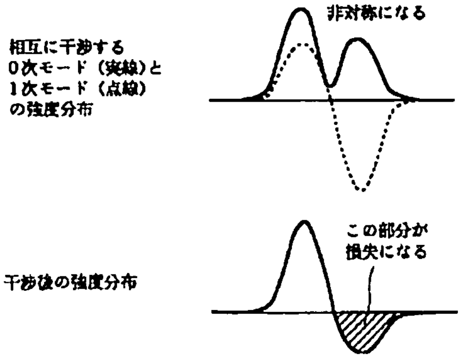

[Translation done.]